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LEAN TRANSITION OF EMERGING INDUSTRIAL CAPABILITY (LeanTEC)

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14. ABSTRACT ***(Maximum 200 Words)***
Lean Transition of Emerging Industrial Capability (LeanTEC) program was a cooperative agreement between the Boeing Company and AFRL conducted from January 1998 to January 2002. The results of this program are documented in the Manual for Effective Technology Transition Processes included as an attachment to this report. This manual provides processes, procedures, and tools for greatly improving technology transition in the aerospace industry. Methodology for the implementation of these improvements is given along with methods for customizing the various processes, procedures, and tools for a given company or business unit. The indicated methodology was tested by the LeanTEC team and results are documented in the report.

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Table of Contents

Table of Contents

List of Figures

Foreword

This volume of the final report documents the technical work performed from December 1998 through December 2002 under Cooperative Agreement F33615-97-2-5153 executed between the U.S. Air Force, Air Force Research Laboratory, Materials and Manufacturing Directorate, Manufacturing Technology Division (AFRL/MLM) and the McDonnell Douglas Corporation, a wholly-owned subsidiary of The Boeing Company. The work was accomplished by The Boeing Company, Phantom Works Huntington Beach, St. Louis, and Seattle; Ford Motor Company; Integral Inc.; Sloan School of Management in the Massachusetts Institute of Technology; Pratt & Whitney; and Central State University in Xenia, Ohio and in association with Raytheon Corporation. The LeanTEC program manager for AFRL is John Crabill of AFRL / MLMP and The Boeing Company program manager is Ed Shroyer of Boeing Phantom Works in Huntington Beach, CA. Financial performance under this contract is documented in the Financial Volume of the final report.

This Technical Volume and attached interactive Manual for Effective Technology Transition Processes are submitted on a CD and the Financial Volume is submitted electronically as a separate file. Paper copies of both the Technical Volume (without the interactive manual) and the Financial Volume of the final report are also submitted.

Executive Summary

The Problem

Technology transition from Research and Development to Product is not done as effectively as it should be in either government or industry. Industry invests an average of 3.5% of sales in R&D ($264B in CY2000). Of the projects that are expected to transition into production, only 20% to 60% do transition. Of those that transition, 60% are either late, have changes after transition, do not meet technical goals, or do not meet cost goals, while 5% of the projects experience all of these inefficiencies. Conservative monetary estimates for losses to industry are over $80B per year in waste and over $300B per year in lost savings. Attempts to improve transition efficiencies over the last decade have had limited success.

LeanTEC Response to the Problem

As a cooperative agreement between AFRL and The Boeing Company, *Lean Transition of Emerging Industrial Capability* (LeanTEC) was formulated to identify processes, procedures and tools to produce a major improvement in transitions of relatively new technologies to existing aerospace products.

The LeanTEC team included key representatives from industry, government and academia.

Government	Industry	Academia
AFRL	The Boeing Company	MIT (Sloan)
C-17 SPO	Ford Motor Company	Central State Univ. (Ohio)
	Pratt & Whitney	Integral Inc.
	Raytheon	

This diverse and exceptionally qualified team performed the following major tasks as part of the LeanTEC program:

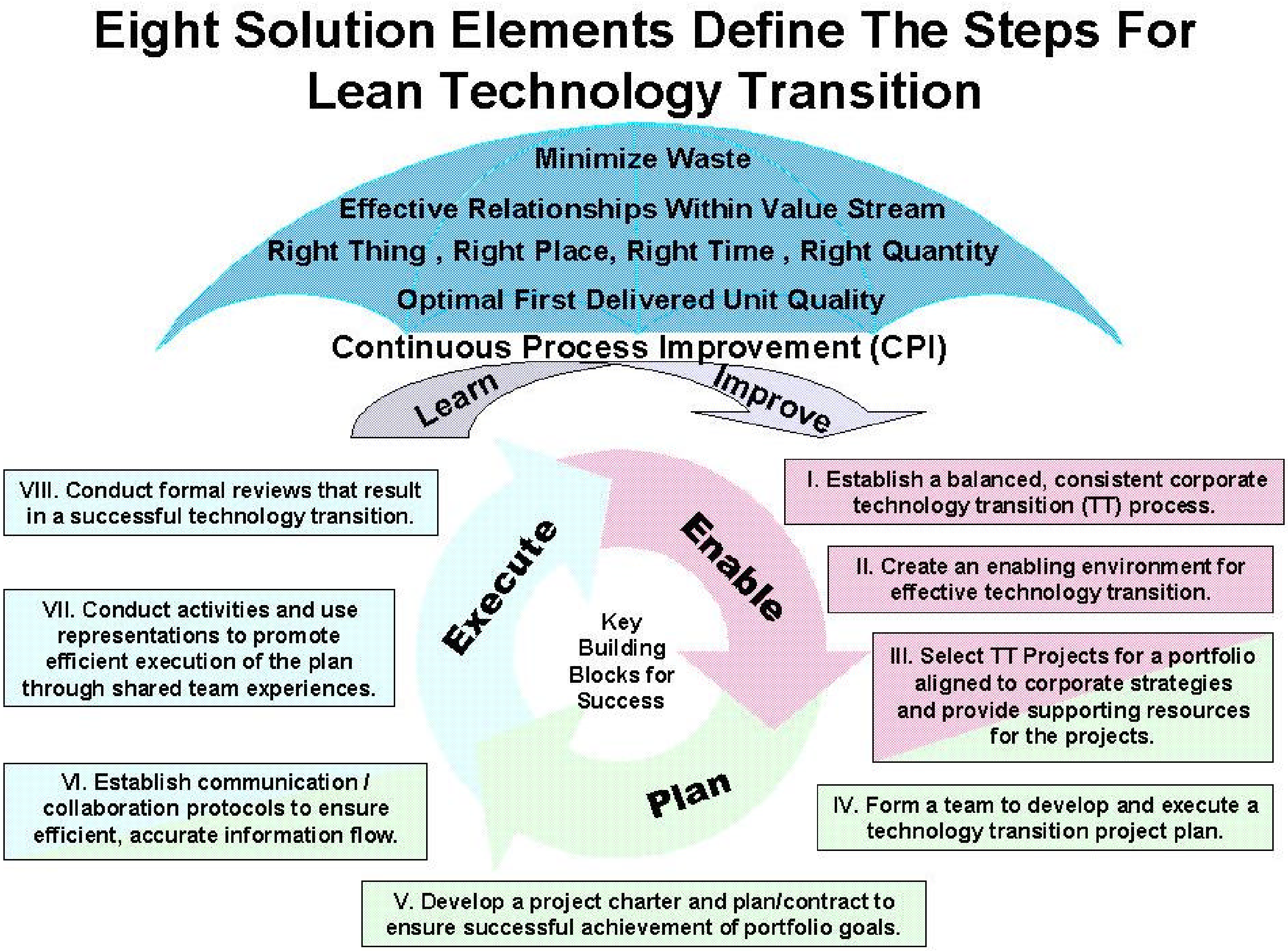
Technology Project Selections - Technology projects, covering a broad spectrum of aerospace development programs, were selected for study throughout the program, from the initial LeanTEC Survey design through the transitioning of pilot projects.

Barriers and Enablers – A preliminary list of technology transition barriers and enablers (used to design the survey questionnaire) has blossomed into a searchable database of over 600 barrier–enabler pairs which is a key finding and deliverable from this program. Technology transition professionals identified each of these as important to some project.

Benchmark Data – Two major benchmarking activities were conducted. 1) an executive workshop with senior R&D executives from 10 major companies and 2) a 135-variable survey administered to technology transition professionals representing about 450 technology transition projects.

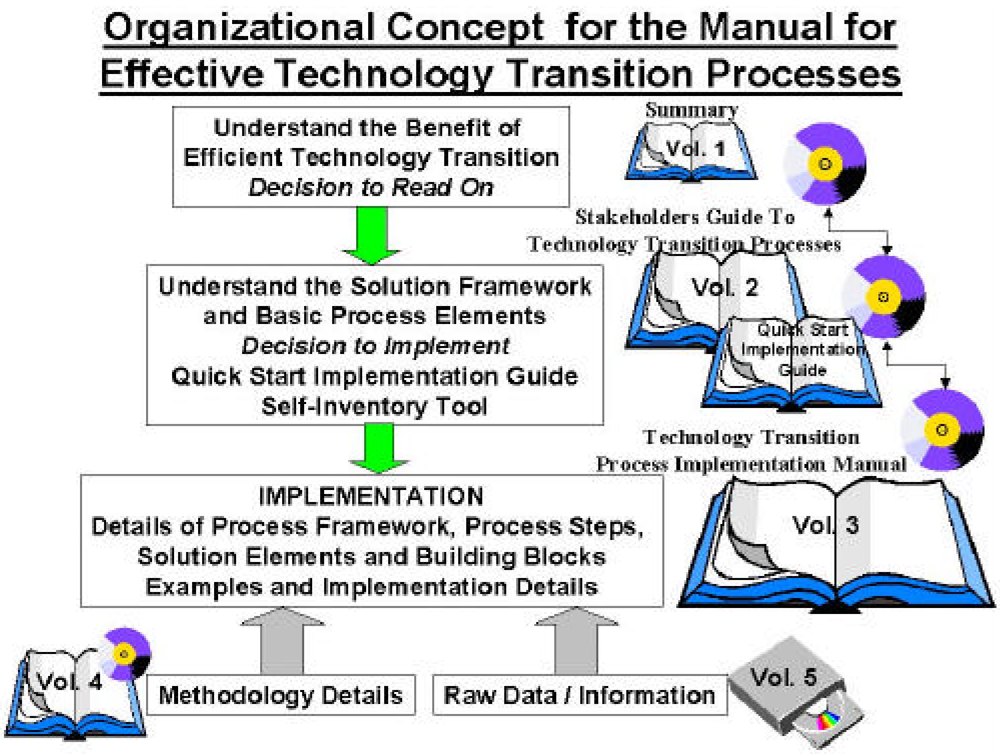
"As-Is" Process - A high-level sequential "As-Is" process was identified from a composite of processes in place at major companies. This provided the key for formulating appropriate questions for the LeanTEC Survey and provided the benchmark for the “To-Be” process.

"To-Be" Process – The "To-Be" process and the associated procedures and tools are the major deliverables of this project. They are documented in the attached LeanTEC Manual for Effective Technology Transition Processes. As shown below, the "To-Be" process is depicted as a three-step cycle of Enable, Plan, and Execute. The eight solution elements that support this three-step process are based on key building blocks for success that can be implemented via best practices. This entire process operates under the umbrella of Lean principles and is connected by continuous process improvement.



Demonstration Pilot Projects – Portions of the "To-Be" process were implemented on a group of pilot projects and in-process measurements were taken. Feedback and lessons learned from experimental implementations were incorporated into the "To-Be" process described in the attached LeanTEC Manual.

Dissemination of Information - LeanTEC program information, including interim results, was provided to both government and industry through a variety of documentation and live exchanges. The substantial findings of the LeanTEC program are presented on an interactive CD as shown below.



<u>**Summary of Results, Conclusions and Recommendations**</u> - This program has provided a methodology for producing breakthrough improvement in technology transition. Further analysis of the substantial data acquired in this program and updating of the processes, procedures and tools with lessons learned from on-going and additional implementations will provide for continuous improvement to sustain the initial benefits. Further development of a comprehensive lean set of metrics for in-process monitoring based on the Capability Maturity Model (CMMI) methods would be a next important step to ensure effective transition outcomes.

Most of the solutions presented here are known, but have been poorly implemented or misused in the past. LeanTEC identified major factors for effective technology transition from the general solution set and provides a path for systematic enterprise-wide implementation using detailed tools and best practices. This new way of viewing the technology transition process using lean principles to eliminate waste, mistake-proof processes, and flow value, while also addressing both technical and people aspects of the process, represents a paradigm shift in thinking built on a substantial and practical database. The LeanTEC solution set proved effective in improving the technology transition process and efficiency for those projects studied.

The attached LeanTEC Manual documents processes, procedures and tools that, when properly implemented, will result in successful and lean technology transitions that will save industry and government billions of dollars each year.

Abstract

Lean Transition of Emerging Industrial Capability (LeanTEC) program was a cooperative agreement between the Boeing Company and AFRL conducted from January 1999 to January 2002. The results of this program are documented in the Manual for Effective Technology Transition Processes included as an attachment to this report. This manual provides processes, procedures and tools for greatly improving technology transition in the aerospace industry. Methodology for the implementation of these improvements is given along with methods for customizing the various processes, procedures and tools for a given company or business unit. The indicated methodology is based on that used by the LeanTEC team is documented in this report.

The results presented in the attached manual are largely based on an extensive examination of actual industry technology transition projects. Both strategic and tactical aspects of technology transition are examined. The overarching umbrella for the proposed improved technology transition process involves Lean principles. Key elements and successful technology transition processes included the elimination of waste, the efficient flow of value and continuous process improvement. A three-step cyclic process is defined with eight solution elements linked to the process steps. The eight solution elements are supported by 72 building blocks for success and 217 best practices for implementation.

The interim results of LeanTEC program have been widely disseminated to various government and industry groups. The feedback from members of these groups has been incorporated into the LeanTEC solution set. Interim LeanTEC results have been implemented on pilot projects. The basic solution set has been validated and lessons learned incorporated into the “To-Be” process as documented in the LeanTEC manual.

The new way of viewing the technology transition process, the use of lean principles to eliminate waste, mistake proof the process and flow value along with the attention to both technical and people aspects of the process represents a paradigm shift in thinking based on a substantial practical data base. The relationship of proper application of the LeanTEC solution set to effective technology transition was demonstrated.

It is concluded that the processes, procedures and tools documented in the LeanTEC manual, when properly implemented and used, will result in successful and lean technology transitions with a potential to save billions of dollars each year.

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"Great discoveries and achievements invariably involves the cooperation of many minds."
- Alexander Graham Bell

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1.0 Introduction

Lean Transition of Emerging Industrial Capability was a cooperative agreement between the Boeing Company and AFRL. This program was conducted during the period January 1999 to January 2002. The purpose of this program was to develop processes, procedures and tools for the successful and efficient transition of new technologies to existing products with an emphasis on aerospace products. One focus of the Boeing proposal was the application of Lean principles to technology transition. This led to the acronym LeanTEC for this program.

A team of experienced industry professionals, academics with substantial experience in the field and customer representatives was assembled. The team used a combination of existing theory and interviews with professionals currently involved in technology transition projects to understand the current process and the major factors that would be dealt with an improved process.

A methodology for establishing or improving the technology transition processes for a specific company or business unit is described in the attached Manual for Effective Technology Transition Processes. This methodology is based on the methods used on a LeanTEC program. Included in the manual are processes, procedures and tools for obtaining major improvements in technology transition at companies engaged in the production and improvement of fairly complex products. The manual provides a mechanism for substantially improving technology transition in a given company through the use of best practices applied to areas that have the major impact on successful and efficient outcomes.

Throughout this report reference will be made to the attached manual. The Manual for Effective Technology Transition Processes contains five volumes. The first four volumes are in PowerPoint format. Volume 1 is a Summary that consists of less than 25 charts that give an overview of the methodology and results of the LeanTEC program. Volume 2, Stakeholders Guide To Technology Transition Processes, contains over 100 charts providing details of the LeanTEC methodology and solution set. The appendix to Volume 2 contains a Quick Start Implementation Guide and a "self-inventory". A quick start guide is a 15-slide brief tutorial on how to get started implementing the LeanTEC solution set. The self-inventory allows the user to evaluate performance on up to 217 best practices and identify the high priority areas where improvement is needed. Volume 3, Technology Transition Process Implementation Manual, provides detailed examples for each of the building blocks that make up the solution elements. This volume, containing over 500 charts, provides the necessary information for implementation of the LeanTEC solution set. Volume 4 details the methodology used on the LeanTEC program with application to the development of customized processes for individual companies and business units. This volume provides the details of the various tasks described in this report. Volume 5 is available only on CD and contains information in the form of reports, draft papers, data files and databases. The files contained in Volume 5 are in various formats including PowerPoint, Excel, MS Word documents and SPSS data files. The electronic version of this manual has a modest interactive capability that allows the user to easily go to specific topics of interest without sorting through the large number of slides contained in this manual. The structure of a manual is illustrated in Figure 1-1.

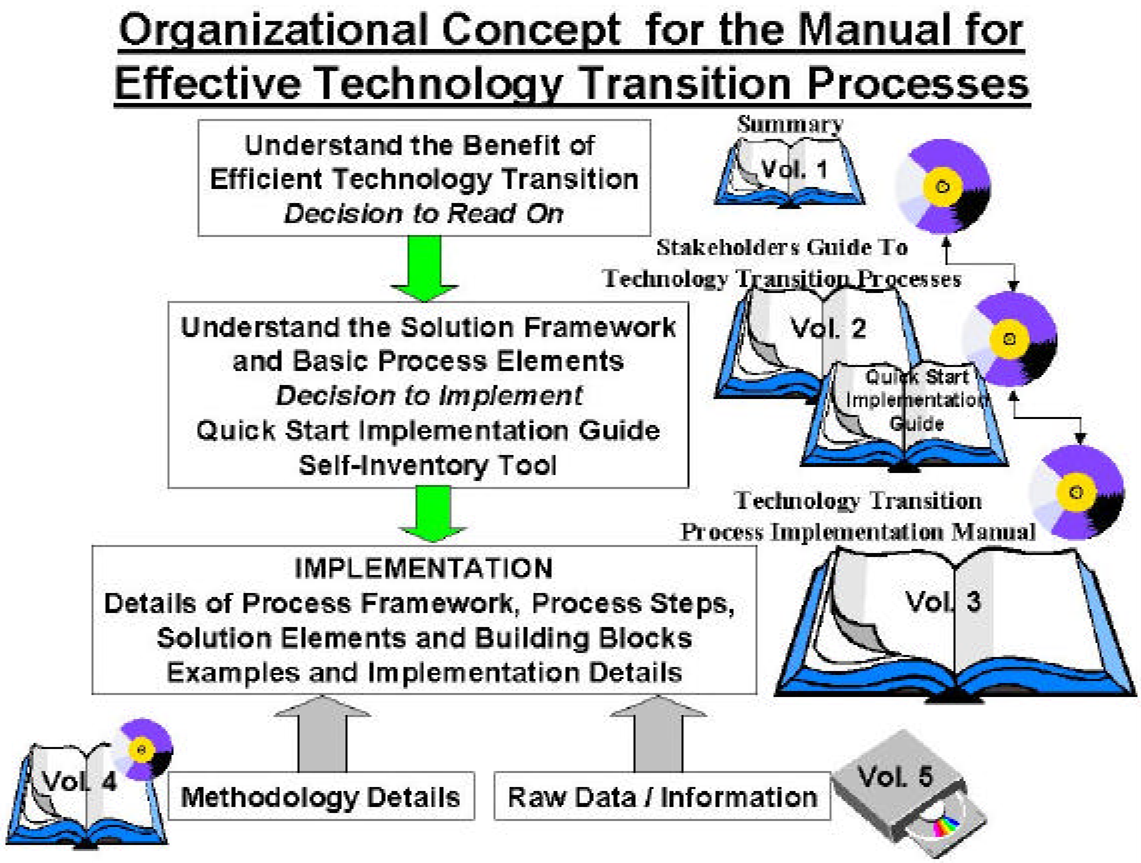


Figure 1-1. Structure of the LeanTEC Manual for Effective Technology Transition Processes

2.0 Problem Statement

In 2000 approximately $264 billion was invested in research and development on new technologies in the United States. Government invested $72 billion, industry invested $178 billion with the rest being invested by academic and other institutions. Benefit is derived from these investments when the technologies are used on new and existing products providing added value to the customers and users. The added value usually involves some combination of higher quality, better performance / desired features, faster development / delivery time, increased safety / environmental benefits and lower price for desired features. The LeanTEC team conducted an analysis of the effectiveness of this investment. Information sources, methodology, assumptions and complete results are given in volume for on the Manual for Effective Technology Transition Processes. Although the net result of this investment was probably positive, the LeanTEC analysis indicated that over $400 billion in waste and lost savings occurred.

Most professionals involved in technology transition recognized that current processes are not as effective or efficient as they should be. For several decades both industry and government programs have attempted to improve the situation. While each of these programs probably resulted in at least a temporary local improvement, it is obvious that much more remains to be done. The attempt by LeanTEC to quantify the impact of ineffective technology transition in terms of dollars and percent of sales should allow professionals to see the magnitude of the problem and potential benefit from its solution.

LeanTEC looks at two aspects of this problem, unsuccessful transitions and inefficient or non-lean transitions. Not all of the funds invested are expected to result in a successful transition in the first year. Approximately 10 percent of the investment is for basic research and development. However, a substantial portion of the investment is expected to produce a successful transition. Estimates of the percentage of projects that successfully transition ranges from 20 to 60 percent (all stated results of the LeanTEC analysis are based on conservative estimates). Failure of intended projects to transition results in a loss of the funds invested (waste) and a loss of expected revenue based on the expected ROI. For projects that are intended to transition over $64B in investment was wasted and over $250 billion in lost potential savings occurred. This represents about six percent of sales for companies investing in research and development.

Non lean transitions are characterized by the fact that of the projects that resulted in transition to product 60 percent were either late, had late engineering changes, did not meet technical goals or did not meet cost goals. Five percent of "successful" transitions had all four of the involved non-lean outcomes. The impact of these non-lean transitions to late implementation and late engineering changes was a wasted investment of $19 billion and lost potential savings of $55 billion, or one percent of sales. These conservative estimates show that ineffective technology transition resulted in almost $400 billion in lost revenue to industry, or about seven percent of sales.

It was observed by one of the LeanTEC team's Air Force advisors that some technologies fly off the shelf onto the target product while other projects take too long to get unto the product or never yield the expected results. This indicates that technology transition from research and development to product is one of the more chaotic processes in business.

In light of the many efforts to improve technology transition processes, a nagging question is why the above problems still exist. In many instances we know many of the right things to do. We either do not do them properly or do not do them consistently. To our knowledge, Lean concepts and principles have not been applied to technology transition. Given the magnitude of the problem, the concepts of waste elimination, efficiently flowing value, and mistake proofing processes, procedures and techniques would seem to have much value. As with many applications of Lean, the implementation is not often done with the entire enterprise in mind nor do the concepts become part of the culture of the corporation and business units. The following two quotations from "*An Industry That Can't Afford Its Future*" by James P. Womack and David Fitzpatrick published in Aviation Week and Space Technology, illustrates these points.

"We are dismayed that 'lean' currently means tactical measures that produce no useful outputs in the form of lower costs and better value for the customer. The problem is simple: There has been no fundamental rethinking of the structure and strategy…...instead, 'lean' has become the latest 'program' sprayed one molecule deep over an existing industry designed for an age now departed."

"We often draw value stream maps in firms that have made serious efforts to apply lean techniques in isolated areas but have little to show for it. The problem is not the techniques or dedication of the managers; it is the failure to apply lean at a system level. When we change the focus to the system, managers suddenly realize many steps are waste, especially organizational handoffs and logistics."

Knowing which of the "right things" that we can do will produce the best outcomes and having a structured way of applying these "right things" consistently with an enterprise view is the key to making large and permanent improvements in the technology transition process. The concept of repetitive application of Lean tools and continuous process improvement can keep the improvements from either returning to the "old way of doing things" or stagnating into another state of wasteful, ineffective activity.

The goal of LeanTEC is to determine the processes, procedures and tools that result in technologies flying unto the product and avoiding behaviors that result in inefficient or failed transitions. Lean concepts such as elimination of waste, efficient flow value and mistake proofing are key factors and the proposed processes, procedures and tools. The total process is cyclic and sustainable through continuous process improvement. The following quotation by Marcel Proust sums up the concept of taking our existing solutions and making them work (paraphrase on one of the main outputs of the LeanTEC executive workshop).

"The real act of discovery consists not of finding new lands, but in seeing with new eyes."

3.0 Solution Process

LeanTEC has developed a manual, described in the introduction, that presents processes procedures and tools for effective technology transition as well as suggestions for implementation. The central basis of the solution is stated in 72 building blocks. These are key items that have been shown by the LeanTEC research to be highly related to effective technology transition. Implementation of these building blocks is accomplished through the use of 217 identified best practices. The 72 building blocks are grouped into eight solution elements. The solution elements are part of a high-level process that covers the entire discipline of technology transition. The solution elements are grouped into three steps – Enabling, Planning and Executing that must be applied with a systemic use of Lean enterprise principles. Implementation of the solution elements provides the framework for either developing a Lean technology transition process for a company or enhancing an existing process. Examples of specific procedures and tools employed by world class companies are given to allow each user to customize the process details for their own culture and goals within the guidelines provided for efficient technology transition. The three-step process is cyclic connected by the disciplined application of continuous process improvement. The intent is not to simply provide onetime local gains, but to establish a culture of sustainable improvement in technology transition resulting in large enterprise gains. The relationships among building blocks, solution elements, the three-step process and the overarching principles of Lean and continuous improvement are illustrated in Figure 3-1.

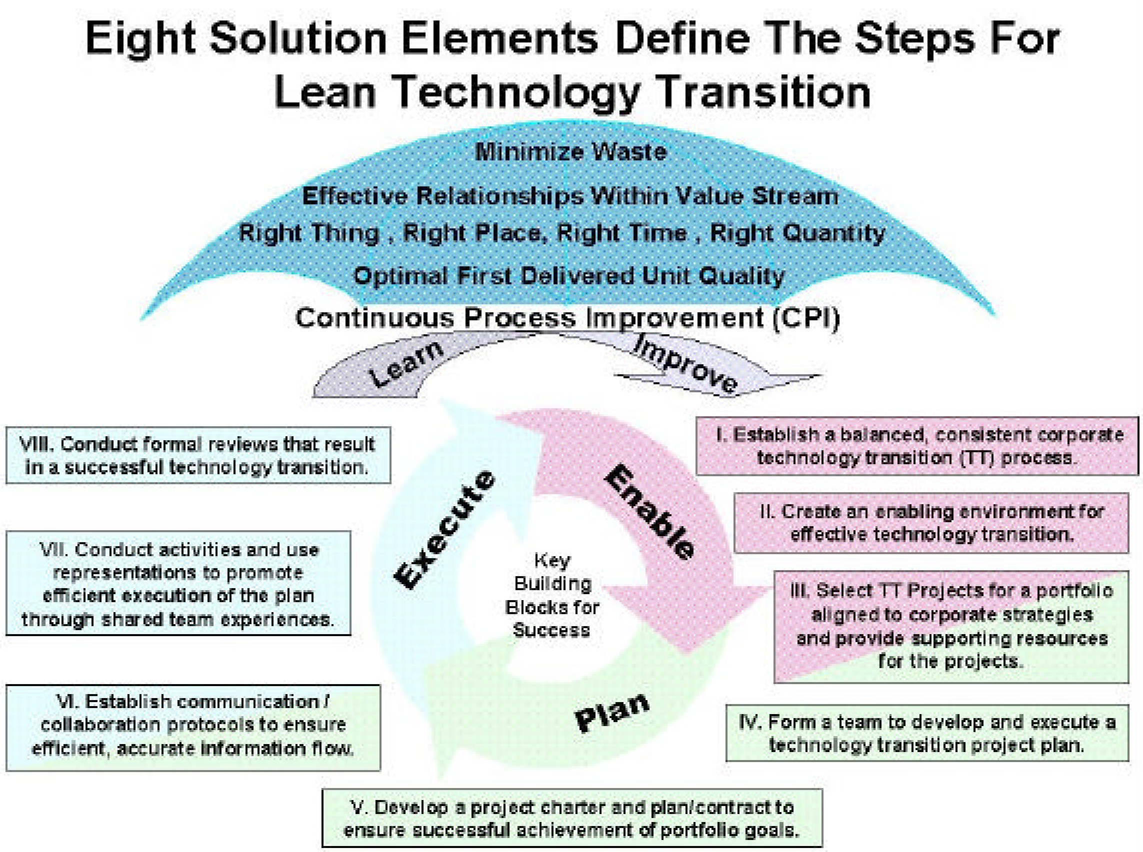


Figure 3-1. LeanTEC Solution Set

The solution elements do not represent new discoveries or a “magic bullet” to allow Lean technology transitions. They are an orderly definition of selected major factors (out of several hundred that were defined) that produce Lean transitions. Small but significant benefits have been observed by applying some aspects of the solution elements locally. The major benefit, as with all Lean processes, comes from systemic application of these findings to the enterprise.

In addition to the information on Lean methods of technology transition, a methodology employed by the LeanTEC program serves as a model for customizing the general information contained in a manual for a specific company or business unit.

3.1 The LeanTEC Team

The original LeanTEC team consisted of McDonnell Douglas, Ford Motor Company, Massachusetts Institute of Technology, Central State University, Integral Incorporated, AFRL Manufacturing Technology, and the C-17 SPO. The acquisition of McDonnell Douglas by The Boeing Company allowed LeanTEC to examine transition processes and projects from McDonnell Douglas (Military and Commercial), Boeing (Military and Commercial), and Rockwell for both aircraft and space projects. Another addition to the team was Pratt & Whitney who brought experience in military and commercial engines for both aircraft and spacecraft. During the last year of the project Raytheon participated as an ad-hoc team member providing project data from their Texas and El Segundo facilities. Most members of a LeanTEC team had over 20 years experience in industry and academia. In addition to the substantial background in research and development and technology transition, team members had access to a large network of professionals engaged in technology transition at various companies. The LeanTEC team provided an industry focus and substantial academic background. This marriage of theory and practice provides solutions likely to work in a wide variety of environments. The final organization chart for the LeanTEC program is shown in Figure 3-2.

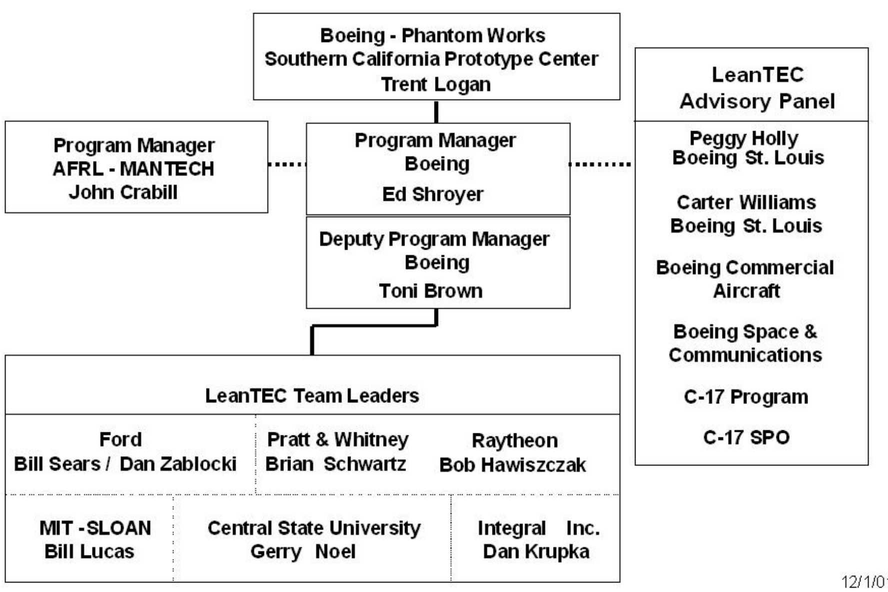


Figure 3-2. LeanTEC Organization Chart in December 2001

During the course of the project, some team members were forced to limit their involvement with LeanTEC due to job or assignment changes. Almost all of the team members who were involved and one time or another with a LeanTEC program maintained an interest in the program and provided valuable inputs whenever they were asked. In addition to those who were assigned as court team members, a significant number of people contributed to the program and in the "LeanTEC sense" were team members. These people in the contributions are too numerous to mention.

The following subsection describes methodology and the various tasks defined in the statement of work in the annual plans. All core members of the LeanTEC team participated to some degree in every task.

Primary responsibility for various tasks was as follows:

Boeing - Team Integrator, Strategic and Tactical Implementation Pilots

MIT - In Depth Studies, Survey Administration, Analysis and Interpretation

Pratt & Whitney - Best Practices, Trial Implementations, Draft Manual Design

Central State University - Literature Search, Barriers and Enablers, Manual Coordination, Manual - Electronic Linking, Web site Maintenance

Integral Inc. - Executive Workshop, Best Practices, Initial Solution Elements Design

Ford Motor Co. - Best Commercial Practices, Process And Methodology Reviews

Raytheon - Manual Review, Solution Elements Structure

AFRL / Mantech - Customer Pull, Government Best Practices, Methodology Review

C17-SPO - Customer Pull, Implementation Feedback, Peer Review

Again, it cannot be stressed too much that all aspects of the program were a true team effort. Each member listed above participated in reviews of the data and the preparation of the manual. One of the main benefits of having full team participation in data interpretation was to have the ability to determine cause and effect using consensus from a variety of experience backgrounds. Many people who were not core team members, both from member companies and other companies who were informed about the LeanTEC program and various briefings and meetings, provided feedback that helped develop solutions that were both reasonable and usable. The depth and variety of experience and diverse perspectives insured solutions that are generally applicable and contain little bias.

3.2 Methodology

The Manual for Effective Technology Transition Processes summarizes the findings of the LeanTEC program. This document is designed to guide either the creation of a new set of processes or the improvement of current technology transition processes by the application of the solution elements and overarching principles though the implementation of the key building blocks.

The experience base used in this Manual covers the technology transition process from the portfolio / project selection of projects that are based on understood principles and have the technology and/or application formulated (a technical readiness level or TRL of 3 based on the NASA standard) through initial insertion in production (TRL 6/7). Many of the principles also apply to activities before and after these process steps.

The focus and experience base used in this Manual is for relatively new technology applied to existing products. Again, many of the principles from the Manual apply to insertion of technology on new products and / or technology transfer from the initial application to other similar applications.

The Air Force statement of work, as modified in the LeanTEC annual plans, provides the outline for both the methodology used in this program and the methodology proposed for customizing effective technology transition processes. The statement of work consisted of these ten tasks:

Task 1 - Selection of Technologies
Task 2 - Barriers and Enablers
Task 3 - Benchmark Data
Task 4 - "As-Is" Process
Task 5 - "To-Be" Process
Task 6 - Developing and Select Phase II Plan
Task 7 - Formulate and Design Experiments
Task 8 - Conduct Experiments
Task 9 - Supplemental Data Analysis
Task 10 - Dissemination of Information

The tasks were not conducted sequentially. Some tasks were performed concurrently and some tasks occurred at several stages of the project. The organization of tasks for customizing it technology transition process is illustrated in Figure 3-3.

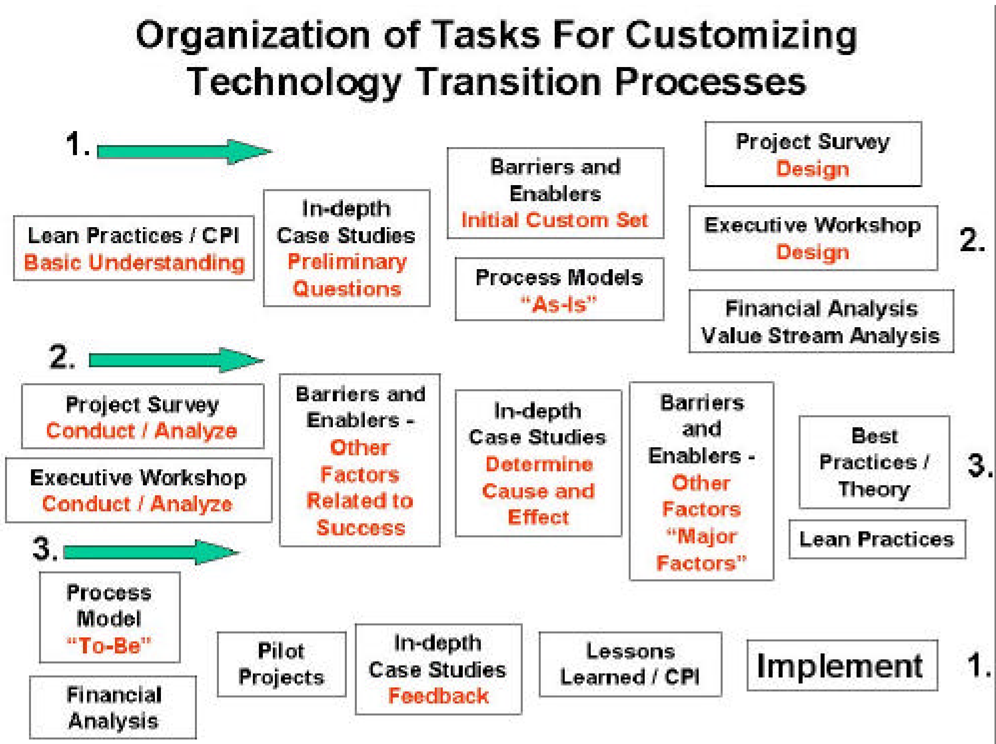


Figure 3-3. SOW Tasks for the Method for Developing a Customized Process

A key factor in the LeanTEC methodology was a focus on real industry projects. Much of the information presented in this report and in the LeanTEC manual was obtained firsthand from the

industry professionals engaged in technology transition. LeanTEC addresses both strategic and tactical factors. Initial studies were based on selected technology projects that were studied in sufficient depth to obtain an overview of issues that helped or hindered technology transition. This was done through interviews with mangers, project leaders and team members.

A preliminary list of barriers and enablers to efficient technology transition was compiled based on the initial interviews, a review of the literature, examination of current theories and the experience of the team. Based on the output from the initial technology project interviews and the initial list of barriers and enablers, the LeanTEC team began compiling a list of questions to be used in an extensive project survey. The development of the survey questionnaire is described in more detail in section 6 of this report and in Volume 4 of the attached manual.

A group of processes, procedures and tools was selected for further evaluation employing a workshop for senior research executives from world class companies, extensive surveys of past projects and further in-depth research on selected technology projects. An overall “As-Is” process was defined and specific attributes of this process for the “average company” were identified from the surveys and the executive workshop.

The items that are highly related to successful transitions, Lean transitions and outstanding performance were selected to define a “To-Be” process including specific procedures and tools for Lean transitions. A group of pilot technology transition projects were selected to evaluate the effectiveness of the application of some of the LeanTEC findings in producing Lean transitions. Interim LeanTEC findings were presented at various conferences and reviews. Feedback from these presentations and reviews were used by the LeanTEC team to refine the building blocks and best practices that lead to the implementation of the solution elements of a “To-Be” process.

The LeanTEC approach is illustrated in Figure 3-4.

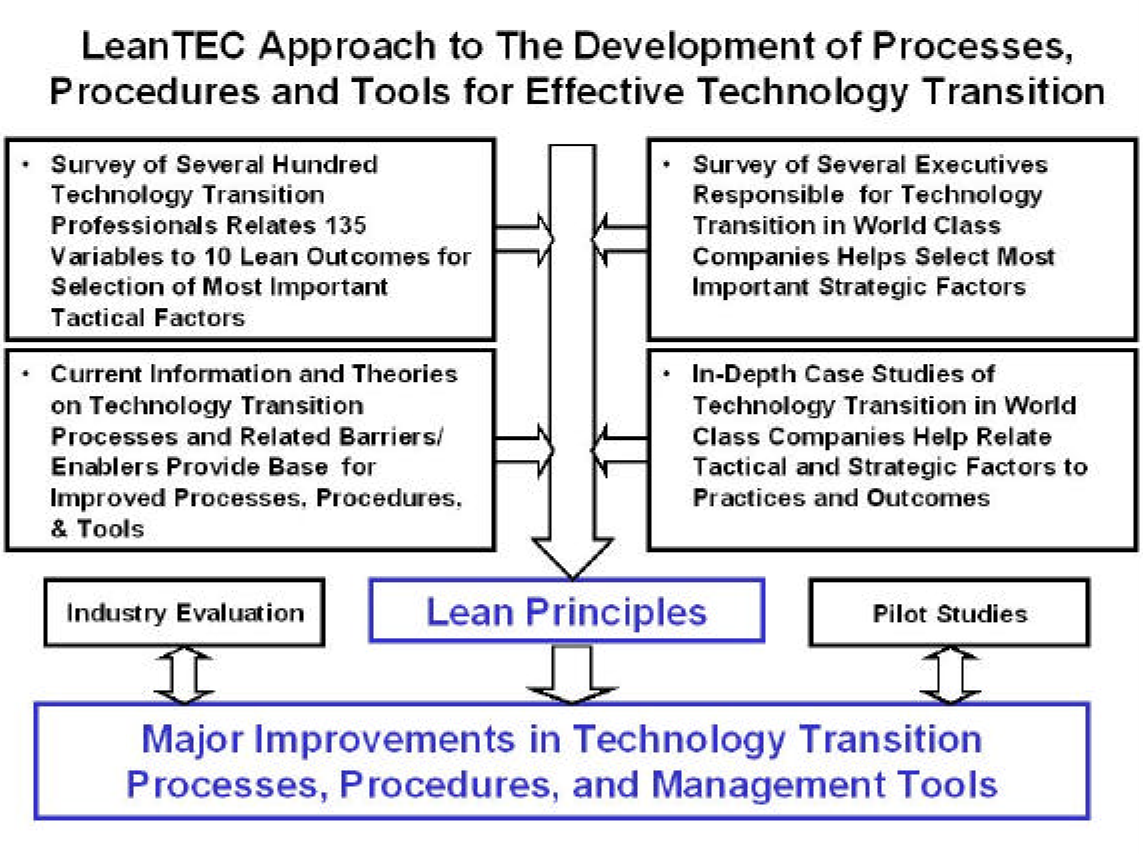


Figure 3-4. Interaction of Task Elements to Produce an Improved "To-Be" Process

A summary of elements of the solution process are presented in Volume 2 of the Manual for Effective Technology Transition Processes and details are presented in Volume 4.

4.0 Task 1 - Select Example Technologies

Since the focus of this program is a transition of technologies to product and the main mechanism of this transition is the technology transition project, various projects and technologies were selected for study throughout the course of the LeanTEC program. These projects covered a variety of technologies with the main focus on structural / manufacturing hardware and processes. The intended applications included military and commercial vehicles, systems, subsystems and parts with both low and high rate production.

4.1 Projects for Initial and "In-Depth" Surveys

Near the start of the program, members of the LeanTEC team selected a group of technology transition professionals for interviews. Students, most of whom had substantial industry experience, from the MIT Management Of Technology program conducted the interviews. The students were used to conduct the interviews to provide a disinterested third party in the hope of obtaining more candid answers than might be obtained if members from the interviewee's company conducted the interviews. A protocol was developed by MIT in an attempt to obtain a consistent set of information from the interviews. Initial case studies consisted of interviews with personnel from a LeanTEC team member company who had taken part in a specific technology transition project (successful or less successful). Personnel who were involved in various aspects of the project over its lifetime were interviewed. The outcomes of the projects were well known, however, each person's view is recorded. The initial interviews were free-form rather than question-and-answer and rely on the interviewer to record specific results based on notes taken during the interview. The project was studied from start to finish from a variety of viewpoints. The resulting evaluation contained both objective and subjective information from an independent analyst. One lesson learned was that it was extremely difficult to keep the person being interviewed focused on structured questions without those questions being in written form in front of him. The students obtained sufficient information to select a few projects for detailed study. The results of the studies are documented in theses that are listed in the references. The information gleaned from these and other projects that did not have dominant success or failure stories form the basis for the future LeanTEC surveys.

They initial selection of technology projects included the technologies listed below. Many of these technologies continued to provide a rich source of information through in-depth surveys and later program stages.

High Speed Machining
Coated Rivets
Composite Materials - Helicopter Applications
Stitched Resin Film Infusion - Aircraft Applications
Stitched Resin Film Infusion - Navel Applications
Stitched Resin Film Infusion - Helicopter Applications
Composite Materials - Tank Applications
Composite Materials - Commercial Applications
Bright Light
Friction Stir Welding – Spacecraft, Aircraft Applications
Precision Assembly
Stretch Form Correction
Composite Horizontal Tail
Agile Automation
Titanium HIP Castings
Spray – On Insulation
Fasteners – Threadless Sleeve, Rivetless Nut Plate, Self Piercing Rivets
Distortion Management
Laser Forming of Titanium
Integral Structure
Pigmented Composites
Augmented Reality
Electron Beam Curing
Super Plastic Forming
Super Plastic Forming / Diffusion Bonding

The “in-depth” surveys of the selected technologies had several purposes depending on the stage of the project. The purposes and methodologies employed are listed below.

<u>Purposes of Surveys</u>

- Identify Major Issues to Use As Variables the General Project Survey
- Understand Processes, Procedures and Tools Currently Employed
- Determine the Cause - Effect Relation of Correlated Survey Variables
- Understand the Impact of Various Building Blocks on Projects
- Understand the Impact of Various Barriers/Enablers on Projects
- Identify Commonly Held Attitudes and Perceptions
- Identify the Impact (Positive or Negative) of Common Behaviors

<u>Methodologies Used</u>

- Interviews using protocols
- Partial surveys focused on specific issues (multiple team members)
- Formal Team Briefings with Feedback
- Gathering Independent Data - Financial, Managerial
- Informal Discussions with Management, Team Leaders and Members
- Pilot Project Observations

4.2 Projects for Major Project Survey

A series of projects surveys was conducted that included gathering information on approximately 450 projects. The survey examined 135 variables with 10 Lean outcomes. Details of the survey will be discussed in section 6 of this report to and Volume 4 of the manual. The participants in the surveys were asked to select a project that they had worked on, that had a definite outcome (either successful or not successful) and that they remembered well. An analysis of the responses showed that the participants selected a disproportionate number of successful programs. This was not unexpected since most people would like to talk about their successes rather than less successful events and tend to have a better memory of pleasant experiences. Figure 4-1 depicts the type of projects reported on that used paper disciplines.

Survey Project Description Summary

What Kind of Projects Were Surveyed?

Technology Description	
Manufacturing	24%
Structure	27%
Subsystems	11%
Electronics	26%
Software	7%
Other	5%

Target Application	
Military Aircraft	30%
Commercial Aircraft	25%
Space Assets	13%
Other	31%
Mixed	1%

13% Basic Research
30% New and Unproven Technology
43% New to the Application

54% New to the Company
28% New to the Company's Product Application

18% Highly Complex
49% Significatly Complex
33% Not Very Complex

	Design Impact	Production Impact
Serious	18%	24%
Significant	49%	50%
Little or None	33%	26%

Duration and Team Size

Project Duration

2%	Less than 6 mo.
11%	Between 6 mo. and 1 year
25%	Between 1 and 2 years
21%	Between 2 and 3 years
16%	Between 3 and 4 years
9%	Between 4 and 5 years
14%	Between 5 and 10 years
1%	Greater than 10 years
	Longest Project 14 years

Team Size

	Members
2%	1
3%	2
6%	3
6%	4
6%	5
30%	Between 5 and 10
21%	Between 10 and 20
15%	Between 20 and 50
4%	Between 50 and 100
7%	Between 100 and 400
2%	Greater than 400

Figure 4-1. Types of Projects Reported on by Survey Participants

4.3 Projects Selected as Pilot Projects

The formulation, design and conducting of experiments using pilot projects, including technology projects selection, will be discussed in detail in Sections 10 and 11 of this report and in Volume 4 of the manual. The projects were selected from ongoing or new start projects being conducted at various Boeing facilities. LeanTEC solution elements were introduced at the project level. Selection of the projects depended on availability, time constraints, and willingness of project and program managers to accept change. The term pilot project was used since no one wants to be the subject of an experiment whose outcome is uncertain. During the course of the experiments projects were eliminated or added as the opportunity became available. Most of the projects which were eliminated were subjected to market or political forces outside of the control of the project

team or team leadership. While the duration of most of the projects did not allow observation of the final outcome during the period of the LeanTEC program, projects were selected on the basis of having a likelihood of significant, measurable progress during the course of the experiments.

The use of a pilot project in a LeanTEC experiment required that at least the team leadership believe that the benefits derived from the application of the LeanTEC principles outweighed the time involved in LeanTEC training and record keeping for the LeanTEC experiments. The ground rules agreed to by LeanTEC pilot project personnel and the pilot project teams were:

- Transition Team Retains Control of the Project
- LeanTEC is Implemented At the Existing Project Phase, No Starting Over
- Lean Means Minimizing Non-Value Added Tasks and Flowing Value
- LeanTEC Monitoring Will Not Result in Excessive Team Time and Effort
- Anything that Impedes Team Progress Will Changed

4.4 Ongoing Technology Selection

During the course of the LeanTEC program new technologies and associated projects became available for evaluation. Some projects from the technology list shown above were terminated, slowed down or had a change in focus. This made it extremely difficult to maintain a consistent technology base throughout the program, but also presented substantial opportunities to obtain additional information. As noted above, technology projects were selected throughout the course of the program for specific requirements including cause and effect analysis and pilot projects. These technology projects and the methodologies used will be discussed further in Sections 6, 10, and 11 of this report and in Volume 4 of the manual.

5.0 Task 2 - Define Barriers and Enablers

Almost every program dealing with the improvement of business processes develops a list of barriers and sometimes includes enablers. The LeanTEC program was no exception. A major difference between the LeanTEC program and most of the barrier / enabler data in the literature is the way the LeanTEC team viewed barriers and enablers and their use in the development of improved processes. It was recognized that all of the barriers and enablers that the LeanTEC team was able to identify were important to someone, on some project, at some time. The question is whether the specific barrier or enabler represents a major factor for technology transition processes for a wide variety of businesses and projects or if it was unique to a specific situation. Other areas of the LeanTEC program, described in Section 6 of this report, were primarily designed to identify the major contributors to outcomes for the general case of technology transition in line with the scope of this program from a large group of potential candidates.

The view of barriers and enablers occurring in pairs, called parameters in the LeanTEC program, led to a different concept of how to deal with barriers and enablers than that generally found in the literature. First, the realization discussed above that all barriers/enabler pairs are not of equal importance. Second, it is not necessary to completely overcome all barriers or to completely implement all enablers to the fullest. Each parameter must be examined to determine its importance to the program at hand and adjusted on the continuous spectrum from barrier to enabler to achieve maximum value flow, minimize waste and avoid critical mistakes or sub-optimization when viewed in the context of other parameters impacting the entire enterprise.

A final factor that sets the LeanTEC effort on this task apart from similar tasks observed in other programs is a sheer magnitude of the information collected. Well over 600 unique barrier and enabler pairs have been identified. This information is presented in Volume 5 of the attached LeanTEC manual in the form of a searchable database. The database is designed to be a useful tool in the implementation of improved technology transition processes and in the solution of specific problems encountered by various technology transition groups during the course of a specific effort. A more complete examination of the methodology and guides for utilization are found in Volume 4 of the LeanTEC manual.

5.1 Barriers and Enablers - Concept

Barriers and Enablers are elements, features or circumstances of the technology transition project environment that can influence the probability of successfully, efficiently and cost effectively transitioning a newly conceived or developmental technology to production. Barriers are generally considered to be undesirable artifacts to be eliminated or circumvented wherever possible. If they cannot be eliminated or circumvented, they may significantly impede or completely “derail” technology transition (TT) efforts. Enablers, on the other hand, are generally considered to be desirable agents to be promoted and incorporated at any opportunity. They can enhance the “flow” of a technology transition project even to the point, in some cases, of ensuring its success. In general, we have found that enablers can be identified or described as the opposite pole of some barrier or vice versa, and that they occur in fact as Barrier-Enabler Pairs as illustrated by the following brief list of examples.

Barrier	Enabler
1. No market need for the technology	1. Strong market pull for the technology
2. TT Team doesn't understand production's problems	2. Production staff members active on TT Team
3. Cost recovery period too long	3. Rapid cost recovery projected

Most barrier-enabler pairs are manifestations of specific attributes or values associated with a more broadly based, and typically neutral, concept that we have chosen to call a '**Parameter**" because it can exhibit either barrier or enabler characteristics (and generally a range of these) under specific circumstances. The following designated parameters illustrate this for each of the barrier-enabler pairs given above.

Parameter

1. Market Receptiveness
2. TT Team Staffing and Skills
3. Return on Investment

These parameters can further be categorized under a more abstract set of concepts, e.g., Market Attributes, Human Resources and Training, and Financial Attributes respectively for the above three parameters, which we have chosen to call "**Factors**". We have used these facts to aid in organizing and categorizing the barrier-enabler pairs in our database as discussed later in this section of the report.

5.2 Uses of Barriers and Barrier-Enabler Pairs

Barriers are potential sources of failure for technology transition processes. However, when used properly they can be tools that facilitate the identification and isolation of causative factors, as well as pointers toward potential solutions. The process of refining an organization's technology transition processes will generally involve identifying the key barriers and their causes, and then putting in place procedures or other features (i.e., enablers) that eliminate or neutralize the barriers as impediments to the transition efforts. For example:

- Analyzing patterns of occurrence of barriers can help identify specific systemic problems.
- Identifying where and when specific barriers occur in the sequence of technology transition steps helps in isolating causes and selecting solutions
- An understanding of barrier concentrations (i.e., their frequency of occurrence at specific points in the technology transition process) is important in developing useful functional models for technology transition processes.

The barrier-enabler database developed under the LeanTEC project is intended to be such a tool for the users of the LeanTEC Handbook. In addition, the barrier enabler database has been instrumental in the development of the elements for the survey instruments that have been used in the basic LeanTEC studies and in the analysis of the results of those studies as well as the results of the pilot project studies. Specific barriers and enablers have played a key role in identifying and elucidating the solution elements that are the foundation of the LeanTEC process.

5.3 Sources and Screening of Barriers and Enablers

The initial group of approximately 150 barrier-enabler pairs was identified by drawing on the expertise and experience of all of the members of the LeanTEC Team and the initial project surveys. Each team member submitted a list of key barriers based on their experience at their respective companies (or, in the case of Integral, Inc. and the academic partners, their experience with a wide range of companies as well as the literature). Based on results of the initial surveys, the results of structured questions on the major survey and "in-depth" surveys based on these findings additional barrier / enabler pairs were identified.

Feedback from various presentations and reviews resulted in more parameters being identified. The inclusion of open-ended questions on key barriers and enablers in each of the surveys (a request to list the top five barriers and top five enablers that the professionals had encountered during their career) provided the potential for an additional 4500 barriers and enablers to be identified. While the responses did not provide the upper limit, a significant number of parameters were stated. These additional inputs have increased the list to a total of over 600 barrier-enabler pairs. In screening the barriers and enablers derived from the open-ended survey questions, an effort was made to make it inclusive rather than exclusive. Consequently, although there are no duplicate barrier-enabler pairs, there are some pairs that are related but exhibit small but important differences. This is one reason for the size of the database. The objective is to make the database as useful as possible by providing details that a user may be able to relate to a specific context that is germane to his/her immediate needs. <u>All of the barriers and enablers were an important factor to some project at some time</u>**.**

5.4 Barrier-Enabler Pair Classification and the Database Structure

The database has been created using MS EXCEL though consideration was also given to establishing it with MS ACCESS. EXCEL was chosen for three reasons: 1) database features of MS EXCEL 2000 are adequate for this application; 2) MS EXCEL is more likely to be available to potential users, and 3) more users are likely to be more familiar with MS EXCEL than with MS ACCESS. The barrier-enabler pair/parameter/factor paradigm was the basis for structuring the primary fields of the database. The "Checklist-Parameter" field was added to provide an expanded version of the enabler property of the parameter in self-assessment / process inventory questionnaires. The following table illustrates the primary field structure of the database with selected examples of corresponding records / entries.

FACTOR	PARAMETER	CHECKLIST PARAMETER	BARRIER	ENABLER
Communication /Information Attributes	Background Information/Homework	Data on alternative solutions is available to the team	Lack of competitive precedent – no information	Database of information on past experience available
Human Resources and Training	Staff Skills and Skill Levels	Professionals with all key skills are readily available to the team	Inadequate skill level on the assigned team	Project is staffed with members having appropriate skills
Human/Cultural Factors	Commitment and Motivation	IPT members are committed to the project's success	Professional and others lack commitment to the team and the process	Professionals are strongly committed to the team and the process

There are currently ten factor categories and each factor has between one and fourteen parameters associated with it. Each parameter, in turn, can have as many as twenty-six barrier-enabler pairs associated with it. A complete list of factors and associated parameters is shown in the following table.

Factors	**Associated Parameters**
Communications/Information Attributes	Analytical Tools/Software Background Information/Homework Co-location Feed-back/Feed-forward Information Resource Maintenance Inter-group Communications Personal Communications Policies and Ground Rules Resource Awareness Strategic Planning and Guidance Technology Plan
Financial Attributes	Corporate Goals Cost-Benefit Ratio Customer Goals Return on Investment
Human Resources and Training	Background Information/Homework Policies and Ground Rules Staff Skills and Skill Levels Staff Training and Experience Staffing Levels and Loading

Factors	Associated Parameters
Human/Cultural Factors	Commitment and Motivation Credibility and Trust Optimism/Realism Parochialism/Adaptability Risk Taking
Institutional Barriers	Security Constraints
Management and Organizational Attributes	Company Stability Continuity Management Commitment and Priorities Management Focus/Emphasis Management Knowledge Base Management Oversight and Guidance Management Policies and Procedures Management Support Market Understanding Organizational Dysfunction
Market/Customer Attributes	Market Exclusivity/Market Share Market Growth Market Receptivity Market Size Market Stability Market/Customer Incentivization
Physical/Material and Capital Resources	Analytical Tools/Software Capital/Funding External Resources Facilities and Other Physical Resources
Technology Attributes	Technology Constraints Technology Durability Technology Ease of Use Technology Performance Technology Readiness Technology Scalability Technology Supportability/Maintenance Technology/Process Maturity Technology-Production Interfacing
Technology Selection, Development Planning, and Process Application Targeting	Project Planning Technology Screening

Database Search and Sort Codes

In addition to the primary fields, several sort-index fields have been added to the database to facilitate searching and reorganizing it for a variety of analytical purposes. There are six major sort-index fields in the database.

1. Location of Barrier/Enabler on Survey Form – this field gives the alphanumeric number (e.g., S1, R1, B18, etc.) of each of the survey questions that relate to a given barrier-enabler pair.

2. Process Step – this field identifies the stages of the technology transition process that are likely to be impacted by a particular barrier or the stage where the barrier is most likely to occur using letter indices A, B, C, and D as follows: A-Technology Selection; B-Technology Development; C-Technology Transition; D-Production.

3. Organization Level – this field identifies the organizational level where a particular barrier is likely to originate or occur using the following letter index scheme: CM - corporate/company management; PM - Program Management; D - department; T - project team; Tm – team members as individuals; S – suppliers; Cu – customer; G – government.
4. Interface – this field identifies interfaces at which specific barriers are likely to play a role using the above letter index scheme in a hyphenated format; e.g., the program management-team interface would be identified by PM-T.

5. Strategic and Tactical Relevance – this field indicates whether a specific barrier-enabler pair is of interest primarily from a strategic or a tactical perspective using the indices STR (strategic) and TAC (tactical).

6. Links to Solution Elements – this field indicates which of the eight solution elements a given barrier-enabler pair is associated with using the solution element numbers (1-8) as indices.

5.5 Use of Barriers and Enablers in Analyses – Correlation Diagrams

There are many ways in which barriers and enablers can be useful in troubleshooting. The following example is related to one of the key findings from the MIT survey activities. The survey results indicate availability of key skills on the team (indicated by responses to survey questions T12 and T18 and shown in the red box in Figure 5-1), are crucial to the success of technology transition projects. The lack of key skills can have a significant impact on key outcomes (per the yellow box). If there is a lack or unavailability of key skills, examples of barriers that could contribute to those conditions are depicted in the blue box. Given a lack or unavailability of key skills, barriers that would occur as symptomatic of that condition are shown in the orange box. The solution element related to this condition is shown in the yellow box in the upper right-hand corner of the diagram of Figure 5-1.

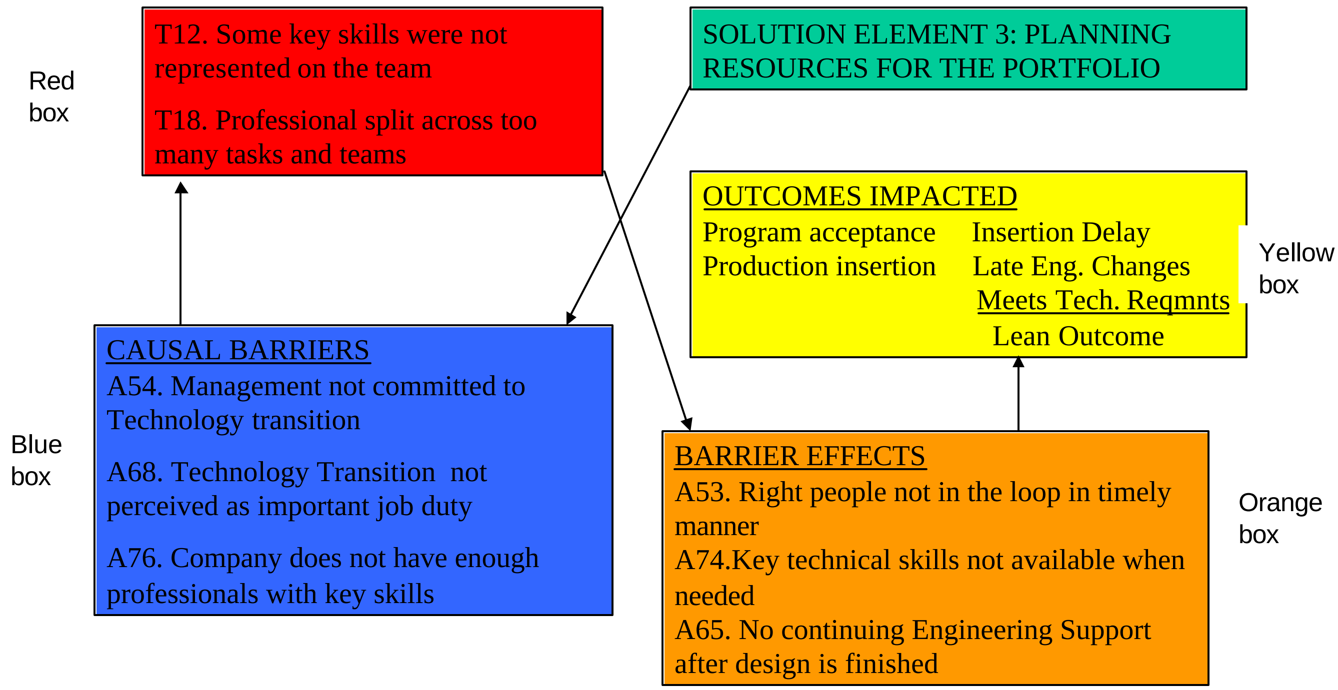


Figure 5-1. Barrier Correlations with Key Survey Results

Figure 5-2 shows parameters that are related to the causative and symptomatic barriers in Figure 5-1. The parameters indicate where and/or what changes could be made to eliminate or circumvent barriers that are contributing to the undesirable condition.

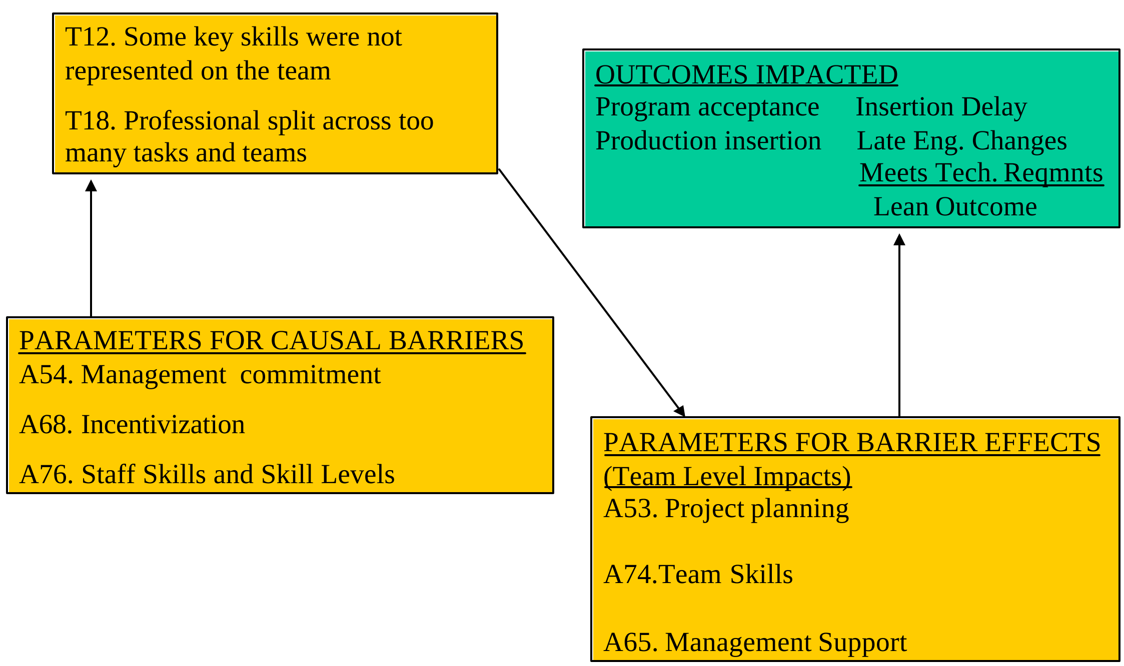


Figure 5-2. Parameters Related to Key Survey Results

5.6 Relative Importance / Occurrence of Barriers

It is difficult to say which barriers or groups of barriers might be most important across a broad range of companies. While there are many commonalties (e.g., the lack of key skills problem out lined above appears to be a common high impact barrier), in general each company has its own unique hierarchy of problem areas. The Solution Elements used in the Manual for Effective Technology Transition Processes are based on those barriers (and associated parameters) that occur most frequently and that have the largest impact on successful outcomes as indicated by the results of the surveys conducted by MIT under the LeanTEC program. An important purpose for the barrier-enabler database is to help identify barriers and parameters that relate to a specific organization's environment, and to link them to the appropriate solution elements that point the way to improving that organization's technology transition process.

6.0 Task 3 - Obtain Benchmark Data

Benchmarking data had two primary purposes. The first was to determine the major factors that "good" or "bad" technology transition processes heading common. The second was to identify industry best practices in the implementation of the major positive factors in technology transition. The original LeanTEC focus was primarily tactical, however, the importance of the strategic aspects and interrelation with the tactical aspects soon became apparent. With us the benchmarking task includes both strategic and tactical elements. In order to define the “big hitters” among the barriers and enablers and establish the details of an “As-Is” process that provided the baseline for the “To-Be” process definition, it was necessary to obtain data on current and recently concluded projects. The LeanTEC approach included examination of current and recent theoretical constructs, literature and the substantial experience of the LeanTEC team, an executive workshop attended by senior R&D executives from ten world class companies, a survey of over 400 projects using up to 145 variables, and in-depth analyses of selected technology projects.

6.1 Theory, Literature, Experience

Examination of theory, literature and experience of the team (both first-hand and second-hand information) was used in determining the factors impacting transition that need more examination through survey and in-depth study. The results of the workshop and survey were also evaluated in the light of past experience from the team and literature as well as theoretical constructs to obtain additional insight and validation. The concepts that "theory informs practice and practice informs theory" were considered throughout the LeanTEC program. Information resulting from surveys or interviews with professionals was examined for consistency with existing theory. Similarly existing theories were presented to professionals currently engaged in real industry technology transition projects to allow the valuation of both the validity of the theory and its importance to the overall problem of transitioning technology to product.

6.2 Executive Workshop

An executive workshop was conducted to obtain information from senior research and development executives at major companies on current issues, concerns, and best practices in the strategic aspects of technology transition. The specific areas covered in the workshop were investment planning, project management and transition planning, and organization design. The executive workshop was hosted by Boeing CTO Dave Swain and moderated by Professor Rebecca Henderson of MIT. Participants included representatives from:

Hughes Research Laboratories
Nabisco
PaceLine Technologies (Lucent spin-off)
General Motors
Ford
DuPont
3M
Rockwell Science Center

Pratt & Whitney

Lawrence Livermore Laboratory
MIT Sloan School
Boeing - Phantom Works
Air Force Research Laboratory
Boeing-Aircraft and Missiles
Boeing-Commercial Aircraft
Boeing-St Louis
Integral Inc.

<u>The major subject areas were:</u>

- Investment Planning
    - How shall we allocate our resources?
- Technology Project Selection - Project Management and Transition Planning
    - How do we manage investments in technologies under development through transition?
- Organization Design
    - How shall we structure ourselves?
    - What incentives shall we provide?

Participants were provided the information on the above subject areas including some preliminary papers by the participants prior to the workshop. Selected participants presented their views on a given subject area. A general discussion of that subject area then followed. The moderator would summarize areas of agreement and differences for each subject area and then attempt to achieve participant consensus. After all three subject areas had been covered, the totality of strategic aspects of technology transition became the subject of an open discussion. The moderator summarized in the chief consensus on the overall session. Details of the workshop along with the final report are in Volume 4 of the LeanTEC Manual.

Discussions on investment planning centered on methods for selecting technology projects. The methods ranged from formal technology councils to providing "poker chips" to product executives and letting them bet on the various technology projects. The common theme in this discussion was the importance of strategic alignment and customer satisfaction.

Discussions on project management and transition planning focused on both metrics and people issues. The discussion of how people in teams should be rewarded for performance was followed by discussion of the need to avoid "punishing" personnel when technologies fail to transition. Several participants expressed the point of view that most of the "failures" that people were being punished for worry that the result of market conditions or the corporate processes and cultures. A major concern was how to match expectations to the investment. How many projects can you do right? When do terminate a project? While no one answer fits all situations, the participants agreed that these items must be dealt with formally and in a way that fits the corporate strategy and culture.
The central topic in organizational design was whether research and development should be conducted by a separate organization and then transitioned to the product organization or whether

the research and development activity should reside within the product organization. The major issue in this discussion was where the funding for research and development came from an how the benefit to specific product organizations could be determined. The consensus was that a separate research and development organization was probably necessary but that close coronation with the customer and the customer focus was certainly required. Another organizational issue, which seems to be a major concern that all organizations, was a capture and transfer of information throughout a large organization. Best practices included technical councils, customer surveys and company listed natural workgroups.

The overall session resulted in several areas of consensus. A key area was that the selection, management and planning processes needed to be well defined, fair, with project inter-actions considered and have minimum transaction costs. The goal was simple, efficient methodologies applied to the understanding of a complex strategy. Another major source of agreement was that the organization, culture and infrastructure should be one that encourages Lean transition by proper rewards and incentives and an environment that is enabling and free from fear of failure. The major conclusion is shown below:

<u>THERE IS NO SINGLE SOLUTION THAT FITS EVERY SITUATION, **BUT** THAT DOES NOT MEAN THAT ALL SOLUTIONS ARE EQUALLY VALID.</u>

- There are a handful of fundamental questions regarding technology management.
- There exist valid, state-of-the-art options for answering each of these questions.
- Each company must select from the available valid options a set of options that fits its history, culture, capabilities, and environment.

These and other findings from the workshop are included in the best practices, key building blocks for success, eight solution elements and Lean umbrella that form the LeanTEC “To-Be” process. This is described in Section 8 of this report and is the subject of the entire Manual for Effective Technology Transition Processes.

6.3 Project Survey

A centerpiece of this project is the survey of a large number of projects using professionals involved at the working level in the actual attempt to transition as the source of information. This survey is described in Volume 4 of the manual with data from the survey presented in Volumes 1,2 and 3. A paper documenting one of the important findings, the relationship of staffing to outcomes, is included in its entirety in Volume 5. A paper describing the details of the methodology, including issues of error analysis is also presented in Volume 5.

The goal of the LeanTEC program was to describe a “To-Be” process for technology transition to product widely applicable to a general class of industries. The process was to focus on the value to the total enterprise and consider the total process flow rather than just local fixes. Looking at the management research literature we found too many predictors of success. Academic standards for rigor, limited time and resources and the modest scale of most management research combine to encourage a drive for narrowly drawn precision of method. Precision is usually best served by the study of a few well-defined factors in a clearly delimited domain testing a clearly stated

hypothesis, and the result is an array of carefully drawn studies that do not aggregate as well as one might wish. One study of teams might point to the clear role of team leadership, and another will carefully document the importance of prototypes, or perhaps the shared use of computer design systems. A third will show that building trust in team member relationships is very important. Such research is usually done well and often leads to the conclusion that some factor was a significant contributor to success.

The difficulty comes when we look across the body of literature and discover that we face the same problem when recommending practices to corporate executives: There are hundreds of factors, all carefully established as important in disparate research settings. We assume that with time a cumulative literature, key factors will emerge, but synthesis is not a strength of the management sciences. These products may weave together persuasive conceptual models and integrated presentations of the importance of families of elements, but hard data on the comparative importance of a large number of different practices is almost unknown.

We believed then that a somewhat different model of research would best serve both theory and practice. Rather than isolating the importance of a handful of important factors, we needed to know which out of a hundred or more factors would, if changed, be most likely improve technology transition across an array of projects. As a consequence, we needed a design to weigh the comparative importance of a large number of explanatory factors found in the literature and raised in our early interviews.

As a consequence, the LeanTEC project chose to collect information on a large number of factors from technology professionals who had participated in a diverse and large number of technology development teams. This drove the ground rules for the instrument and survey design. Rather than interviewing a number of participants on each project to increase precision, we elected to rely heavily on the report of a single individual who knew each project well, and to add more and more additional cases rather than multiple observations per case. Instead of limiting the projects studied to a set of similar projects, we included a wide variety of technologies and projects. Not all of the potentially important factors involved in development projects could be included, but we chose to push the limit of how many factors we would include.

The practical implication was that we had decided to sacrifice precision for breadth of inclusion, and we prepared for analysis of variables with a high measurement error. We chose to accept the compounded risks of relying on a single informant per project, and using only one or two questions for many concepts. To compensate, we took steps to increase the reliability of the data collection process, and rely on the power of numbers.

6.4 The Survey Instrument

The physical design of the survey instrument and the wording and organization of the questions to obtain valid responses is accomplished by MIT. The content of the survey was a full team effort. Guided by the initial technology project surveys a full instrument was developed by the team. A large number of variables was initially identified and then, limited by size, reduced to the final number by team consensus. The primary data collection tool was a paper and pencil questionnaire

that individuals completed under research supervision in small group sessions supervised by research staff.

Factors identified as potential drivers behind team performance included in the study included: 1) technology and initial project characteristics (39 factors), 2) team location, team culture, and processes (33 factors), 3) types and timing of use of work activities (60 factors), 4) management polices and team resources (23 factors), 5) barriers encountered (25 factors), and 6) outcome questions. In all, some 155 factors were examined to see if they related to barriers and project performance. They included:

- Collocation. Team proximity was probed by a question that asked what proportion of the team was within a one minute walk, (from Allen's work on proximity and work on proximity and communications), in the same building, and how close the team was to production facilities where the design would be put into practice.

- Team leadership. Informants were asked how effective the team leader had been in resolving technical differences, the leader's technical competence, and ability to obtain resources and administrative skill.

- Staffing and team member characteristics. Question were asked about whether development team members had production experience, team size, what number were full time, the level of over-commitment of the team members and whether the team had all the key technical skills on it that were required.

- Social relationships. While we could not get at such things as trust directly, we asked what proportion of the team had worked together before, and how well they got along personally during the project. An external measure of alignment was how often the team had gone to management to resolve team differences.

- Communications and shared work. Data was collected on use of prototypes, computational tools, risk analysis, business planning, and other work activities.

- Resources and external technical support. Here we included questions about the uncertainty of the project's funding, whether they had access to the right equipment, whether it was receiving support from the customer program, whether it knew where to find help elsewhere in the company and the quality of the support

- Barriers encountered. A battery of barriers reported to have been important in the past was offered to determined whether the problem had arisen far a particular team, and if it had how much effort had gone into addressing it.

- Outcomes. Questions were about successful insertion, project delay, late engineering changes and meeting both cost goals and technical requirements.

The instrument was designed to minimize subjective memory bias where possible by using questions that asked about behaviors and activities that were more readily remembered. Where the concept and creative ability permitted, questions were crafted in terms of observable behaviors

rather than classical attitude items. Thus instead of asking about a more subjective question about team alignment of purpose and how much agreement there had been on technical issues, we asked how often they had gone to management to have differences on the team resolved. To determine the effectiveness of the team's members in maintaining the balance between the team's internal work and representing the concerns and standards on their home departments, we asked whether home departments had rejected the team's ideas and how much effort had been required to deal with that resistance. Such stressful activities are usually long and well remembered, and we believed that this kind of question would provide more reliable measures.

The entire survey is presented in Volume 4 and examples of the survey are given in Volume 2 of the attached manual. Some representative questions along with the instructions are presented here to give the reader a feel for the type of survey that was conducted.

The survey instrument consists of two parts. Part One was to be filled out by the participant prior to coming to the survey session. However, time was allocated in the session for those who had not completed this part. Part Two was completed at the survey session. Instructions for both parts One and Two are shown below.

Survey of Team & Organizational Factors in Effective Technology Transition

PART ONE

The Boeing Company, Pratt & Whitney, Ford and other companies are cooperating in a project supported by the U.S. Air Force to understand how new technologies can be developed and transitioned to production systems more efficiently. The purpose is to gain a better understanding of how we can improve the ways we develop and insert new technology into product and production systems.

You are one of many professionals we are asking about barriers to and enablers of effective technology transitions in their organizations.

Your participation is strictly voluntary. You may decline to participate at any time, or you may simply choose not to answer any questions that make you uncomfortable. Because this is a survey of the professional judgments and opinions of individuals, let us stress that any information you do choose to provide will be held in strict confidence. Your name cannot be attached to this survey, and the raw information is sent to MIT where it will be summarized. None of your answers can be linked back to you.

Participants in the survey and others at each company will only see the aggregate results of the interviews. You may request a copy of the summary report of the findings by providing your business card, or providing a separate sheet of paper with your name and address information, including your e-mail address.

There were 13 questions P1-P13 (some multiple part) concerning the nature of the project.

Example:

P3a. What was the state of the art of this technology?
___ Technology was **radically new**.
___ Technology **new and unproved**.
___ Technology was in use somewhere but it was was **new to this kind of application**.
___ Technology was used somewhere for similar applications and **was well understood**.

P3b. More specifically, how new was the technology to your company? Was the technology:
___ **New and unproved** in your company?
___ Technology was used in your company but it **new to this kind of application**?
___ Technology was used in your company for similar applications and **was well understood**?

A timeline showing when various phases of the project occurred is also included in Part One. This data has not been fully coded. Selected sections of Part Two are shown below.

Survey of Team and Organizational Factors in Effective Technology Transition

PART TWO

9 Questions on Strategy, S1 - S9 - Example

Technology Selection/Project Start. Here is a series of statements about the project you are reporting on. Please circle a number to indicate your level of **agreement or disagreement** that each statement is a description of team processes on this project when the Development Stage started:

	Strongly Disagree	Disagree Somewhat	Not sure, Don't know	Agree Somewhat	Strongly Agree
S9. The team knew how the project fit into corporate strategy and goals.	1	2	3	4	5

8 Questions (some multiple) on Project History and Location, H1 - H8 - Example

H3. **During the Development stage**, roughly how many people were on the team?
H3a. Of these, how many were on the team full time? ______

22 Questions on Team Dynamics, T1 - T22 - Example

Team Participants & Communications during Development

Here are some statements about the people on the project and the way they worked together **during the Development stage**. Please circle a number to indicate your level of **agreement or disagreement** that each statement is a description of team processes on this project.

	Strongly Disagree	Disagree Somewhat	Not sure, Don't know	Agree Somewhat	Strongly Agree
T13. The team members got along well personally.	1	2	3	4	5

10 Questions on Resources and Tools, R1 - R10 - Example

Resources and Tools during Development

Here are a series of statements about the availability of resources and supporting tools. Please select your level of **agreement or disagreement** with whether each statement is a description of your project **during the Development stage.**

	Strongly Disagree	Disagree Somewhat	Not sure, Don't know	Agree Somewhat	Strongly Agree
R5. There was a lack of resources for prototypes, test gear, etc.	1	2	3	4	5

13 Questions on External Environment, E1 - E13 - Example

External Project Environment during Development

Here are statements about **how the project related to its outside environment**. Please circle a number to indicate your level of **agreement or disagreement** that each statement is a description of this project **during Development**.

	Strongly Disagree	Disagree Somewhat	Not sure, Don't know	Agree Somewhat	Strongly Agree
E8. The project was a management priority.	1	2	3	4	5

18 Questions on the Frequency of Various Activities, F1 - F18 - Example

Activity Report during Development

How often did the team members do the following?

(If you feel the activity is Not Applicable to your project, check NA.)	Never	Once or twice	Several times	Many times	NA
F3.Had formal progress reports & discussed schedules at team meetings.	____	____	____	____	(__)

The following apply only to situations *inside and outside* the project where meetings and informal discussions included personnel from Production and/or a Program (the owner of the target system that will rely on the technology).

	Never	Once or twice	Several times	Many times	NA
F10. Passed around physical prototypes of various kinds during discussions.	____	____	____	____	(__)

21 Questions on When Various Activities Occurred, W1 - W21- Example

The following questions rely on the timeline and flow of the stages of technology for your project that you were sent in advance of this session.

Referring to your timeline , **PLEASE CHECK ALL STAGES THAT ARE APPROPRIATE**.

General activities

WHEN were the following activities carried out by the team? (Please **check as many stages as are appropriate.**) For example, if W2. Procurement was initially involved in the Selection/Planning stage, dropped out, and then came back in for Transition/Pre-production and Production, check (✓) in the first, third and fourth columns.

	Selection	Development	Transition	Production	(Never)	(NA)
W1. When did production representatives participate regularly?	___	___	___	___	(__)	(__)

Relationship & Activities between Design & Production

The following apply only to situations where joint meetings and informal discussions **included both**:

1. Professionals from the Research, Design, and Engineering communities concentrating on developing the technology (referred to broadly as "Design"), and
2. Professionals from the Production community **and/or** the Program (the owner of the target system that will rely on the technology) responsible for its implementation (referred to broadly as "Program & Production.")

Referring again to your timeline:

WHEN were the following activities carried out? (PLEASE CHECK AS MANY STAGES AS ARE APPROPRIATE.)

	Selection	Development	Transition	Production	(Never)	(NA)
W16. When did Design and Program & Production professionals have unscheduled & informal **joint** conversations about the project?	___	___	___	___	(__)	(__)

25 Questions on Barriers, B1 - B25- Example

Problem Solving and Team Resources

Here are a series of statements about problems that are said to occur with technology development. For each statement, we are asking you to make two separate judgments to help us understand what problems require substantial team effort:

❶ First, did this problem ever come up in the specific project being reported on? If "No", then no other information is requested, and move to the next statement.

❷ If "Yes," how serious was the impact of this problem on the process of the project's work? Here we are concerned with **how much effort** in attention, time and energy did the project have to spend solving , correcting or compensating for this problem and its consequences.

If a problem did come up, did dealing with it require "Very minor effort," "Minor effort," "Significant effort," "Major effort," or "Very major effort"?

❶ Did this problem come up during this project?	No.	Yes. The problem came up. ❷ IF YES, how much project effort had to be spent on this problem? Very minor effort effort	Minor effort	Signif. effort	Major effort	Very major
B1. It was harder than expected to take the risk out of the new technology.	0	1	2	3	4	5

10 Outcome Questions O1 - O10

Project Outcomes

O1. Program Acceptance. Was the project accepted by a Program to be put into Production? (If not applicable or can't remember, check here___) This is initial program **acceptance**, not whether it was actually ended up in production.

___ 1. No. The technology has been abandoned. ___ 3. Ideas/parts of the technology were accepted. ___

2. No, but technology is on the shelf for future use ___ 4. Yes, the technology was accepted for production.

Here are seven statements about how the project was handled. Please circle a number to indicate your level of **agreement or disagreement** that each statement is a description of this project.

	Strongly Disagree	isagree Somewhat	Not sure, Don't know	Agree Somewhat	Strongly Agree
O1a. The project was terminated too soon.	1	2	3	4	5
O1b. Lessons learned were well documented for future use.	1	2	3	4	5
O1c. The project continued long after it should have been abandoned.	1	2	3	4	5
O1d. The wrong technology was chosen for development.	1	2	3	4	5
O1e. The target application was a poor choice for the technology.	1	2	3	4	5
O1f. Circumstances had changed, changing the need for the project.	1	2	3	4	5
O1g. A strong business case could not be made for implementation.	1	2	3	4	5

O2. After the project team thought the technology was ready, was there any delay in getting a decision to move the technology into the Transition/Pre-production stage?

___ No delay ___ 1 to 6 months delay ___ 7 to 12 months delay ___ Over a year delay
___ Project canceled too soon to know ___ Not applicable to this case ___ Don't know

O3. **After the project reached Transition/Pre-production**, how many additional changes in the designs and processes were required before the application was ready for production?

___ Many serious changes ___ Significant changes ___ Minor changes ___ None, or almost no changes
___ Project canceled too soon to know ___ Not applicable to this case ___ Don't know

O4. Was the technology **eventually inserted into production** ?
Note this is whether the technology and its application were part of the full production of systems.

___ No. The technology has been abandoned. ___ Ideas/parts of the technology were used.
___ No, but the technology is on the shelf for future use ___ Yes, the technology was used in production.

O5. **After the project reached Transition/Pre-production**, did the project go to production as quickly as it should have?

___ No delay ___ 1 to 6 months delay ___ 7 to 12 months delay ___ Over a year late
___ Did not reach production, was not implemented ___ Not Applicable ___ Don't know

O6. **After the project was actually in Production**, how many additional changes in designs and processes were required?

___ Many serious changes ___ Significant changes ___ Minor changes ___ None, or almost no changes
___ Did not reach production/ was not implemented ___ Not Applicable ___ Don't know

O7. Did the new technology as it was implemented meet the project's cost goals?

___ The results met or exceeded cost goals ___ Did not reach production, was not implemented.
___ The results came close to achieving cost goals ___ Not applicable.
___ The results fell far short of achieving cost goals ___ Don't know.

O8. Did the new technology as it was implemented meet the project's technical requirements?

___ Results met or exceeded technical requirements. ___ Did not reach production, was not implemented.
___ Results came close to achieving technical requirements. ___ Not applicable.
___ Results fell far short of achieving technical requirements. ___ Don't know.

O9. Looking back at where the technology was when the project started, how ready was the technology?

___ Ready. No new work of any kind was required on the underlying technology.
___ Ready, although some work on the technology was required specific to the new application.
___ Mostly ready. Some additional basic development was required on the underlying technology.
___ Marginally ready. Substantial work was required on the underlying technology.
___ Not ready. Very major basic development work was required and/or the project was stopped.

O10. Setting aside questions of schedules and budgets, **how successful was the project in its over-all and long term benefit** to the company?

___ Very successful ___ A substantial success ___ A limited success ___ Not successful

O10a. Did this project make any particular contributions not captured in the questions above? If it did, please provide 5 to 10 words describing that benefit:

7 Information Questions I1 - I7

I1. Now that you have had a chance to think about the project and provide some answers, how well do you think you remember the details of the project? Are you: (Check ✓ one.)

___ Very confident that you still remember the project well?
___ Fairly confident you remember the main things well, but not as confident about the details?
___ Not confident of your answers, so we should only use your answers with caution.

I2. Here we would like to know something about your background. (1) Please check what your primary role and level of management were at the time of the project you have just reported on. (2) Then check what your primary role and level are today.

Your primary role:	AT THE TIME OF THIS PROJECT (a1) Role	(b1) Management level		TODAY (a2) Role	(b2) Management level
General R&D	___	Executive	___	___	Executive
Manufacturing R&D	___	Middle	___	___	Middle
Engineering design or analysis	___	First level	___	___	First level
Manufacturing engineer	___	Was not a manager	___	___	Not currently a manager
Production/tooling/assembly	___			___	
Cost analysis/planning	___			___	
Procurement/contracts	___			___	
Quality/testing	___			___	
Other (Please specify: ________)	___			___ (Please specify: ________)	

I3. Have you ever led a project team? ____ No ____ Yes, for a small effort. ___ Yes, for major project.

I4. How many different major projects have you been involved at your current company?
___0 ___1 ___2 ___3 ___4 ___5 ___ 6 or more

I5. What division were you in?

In general, looking across all your experience in attempting to transition technology to production:

I6. What have been the four or five most important barriers to efficient technology transition.

I7. What have been the four or five most important enablers to efficient technology transition.

6.5 The Interview Process

Assuring a quality data collection process required that special attention be given to motivating the participants. There was widespread upper, middle and first line supervisory buy-in to the research, and participation was widely encouraged. Management told professionals that this was important research to their company and they were encouraged to participate. Respected members of the technical community at each locale who had nominated participants also encouraged their attendance at a data collection session, and added their voices to the belief that the results would indeed have meaningful results for them and their company.

The second section was given to the informants to be self-administered in meetings of small groups. The research began the session by stressing general instructions, questions were answered, and there was frequently considerable discussion of key concepts like our definition of "team." It was repeatedly emphasized that their answers were to apply only to their chosen project, and depending on the section, to particular stages of the project as defined by their timeline. Unlike a traditional questionnaire, the individuals were instructed never to guess, to feel free to say questions were not applicable to a particular project, and to write comments and explain answers if they had doubts about the meaning of questions. In general the tone was that we were soliciting facts about the team process, not opinion, although certainly many parts of the instrument are subjective in nature.
After the self-administered interview process was started, research staff would interrupt the process when the group arrived at particular points in order to stress additional instructions to minimize any

misunderstandings. Near the end of the process, renewed stress was placed on not guessing on outcome questions which is marked by a somewhat higher amount of missing data for those questions, a measure of how seriously the informants took the process. The average time to complete the instrument was just over an hour, but it ran to 80 to 90 minutes for informants who came to the sessions without having completed the first part in advance.

There were a variety of indicators that the informants were indeed motivated and careful. Of almost 400 instruments collected to date, only two were turned in that were substantially incomplete. Many surveys were dotted with additional comments and explanations, testifying to the care being taken with the answers. A last measure of informant involvement is that when individuals completed the instrument ahead of others, they were free to go but they were invited to return for an open discussion and a short briefing of the results of earlier work on the project. Roughly 80% of the informants stayed or returned to participate in this final part of the session.

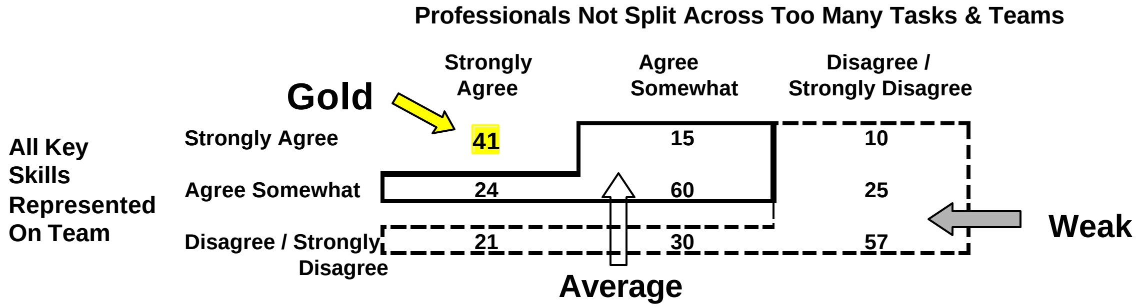
6.6 Analysis of Data

The completed surveys were retained by MIT personnel for coding and initial analysis. The analyzed data for a specific company or business unit was reported to that business unit along with summary data from the other surveys. LeanTEC team participants have access only to the summarized data that had been coded to minimize the possibility of identifying the company, the project or the participants. The coded data was entered into an SPSS file at MIT. SPSS is a comprehensive software system for data analysis from SPSS Inc, Headquartered in Chicago IL - http://www/spss.com. For this analysis project SPSS version 10 was used. A full SPSS data set is given in Volume 5 and a comprehensive description of the analysis methods is in Volume 4 of the manual.

Filtered Cases - The database could be filtered for specific cases - for example only projects that where the respondents “strongly agreed” that “the project was a management priority” would be a data subset. Filtering for multiple factors requires a very large quantity of data. Some cells are reduced to 0 or single digit entries after only 3 filter factors are applied.

Frequencies / Descriptive Statistics - Since most of the data are Ordinal rather than numeric traditional statistics such as the mean and mode are not applicable - Frequencies generally reflected the percent of responses in each answer category (strongly agree, agree, etc.) or derived category (transitioned, did not transition or gold, not gold). Gold is the term used in the LeanTEC manual to describe a best practice. In the discussion on cross-tabulation the use of the term "gold" is shown in the context of survey results. In the example "average" and "weak "categories are shown. For most analyses the average and weak categories are defined as "not gold".

Cross-tabulation - The cross tabulation gives the array of responses of two variables with number of entries or percentages shown in each cell - An example of the cross tabulation for “all key skills on a team” and “professionals not split among too many tasks and teams” is shown below.



The cross-tabulations form the basis for the definition of major factors and, using filtering, the determination of major factors for specific classes of programs. A bi-variate correlation analysis was used to determine the relationship, if any, between variable pairs. Of particular interest is the relationship of various variables to the outcomes. The relationship between variables and outcomes for filtered sets is important to the identification of major factors under specific conditions. For example - collocation may be related to lean outcomes for well-staffed teams but not for poorly staffed teams.

The Kendall tau-b statistic was used to examine correlation of the ordinal variables. This statistic indicates a trend relationship (positive or negative) between the entries on the cross- tabulations. The significance of the result indicates how often the pattern given in the cross-tabulation would occur by chance. Examples of correlation and test of significance for the O4 outcome, “Accepted in Production” and several other variables including O4 and other outcomes is shown Figures 6.1 through 6.3. The identification of major factors is illustrated in the following charts.

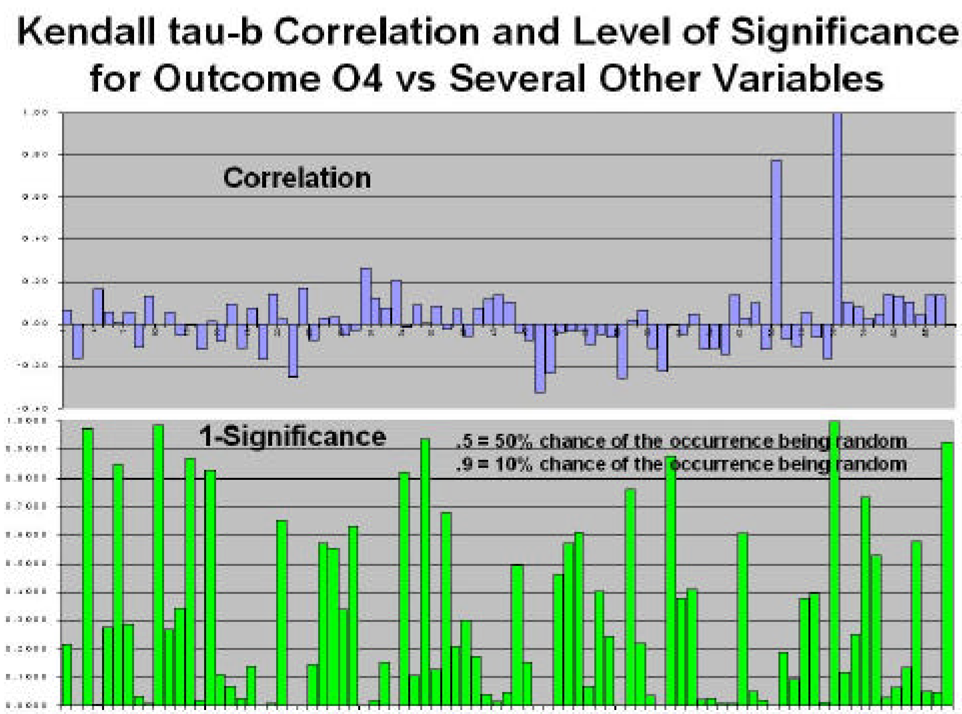


Figure 6-1. Correlation and Significance Data for Example Analysis

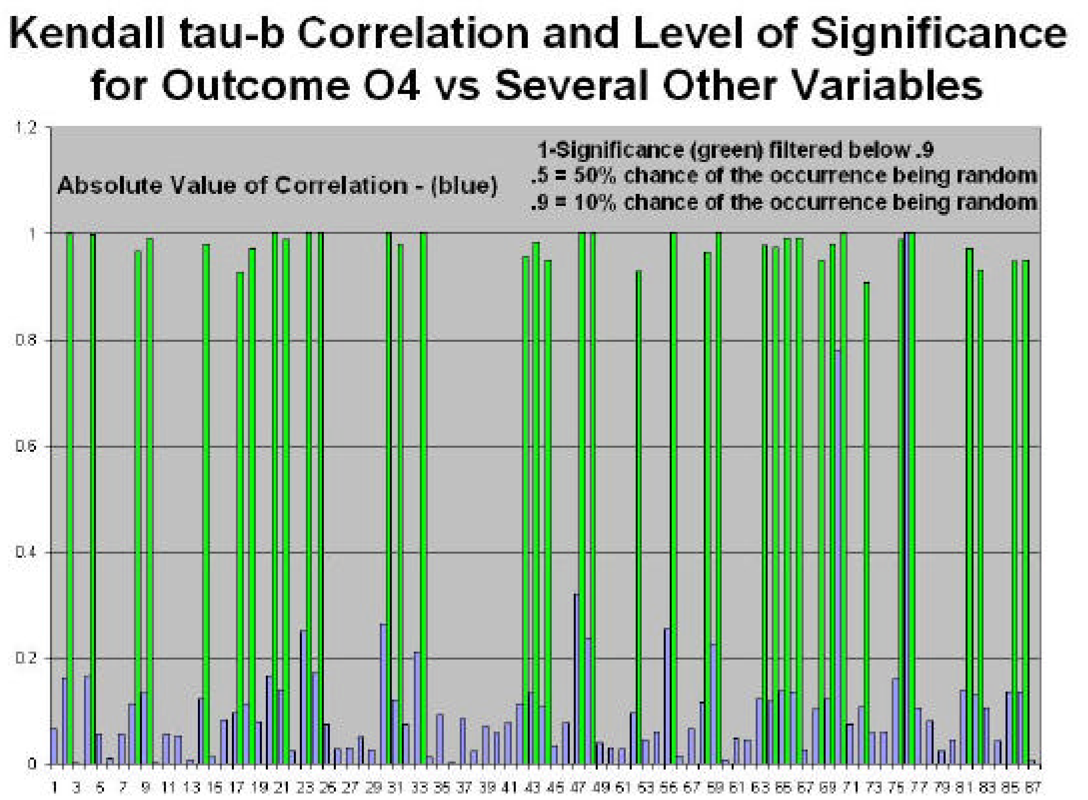


Figure 6-2. Picking the Major Factors

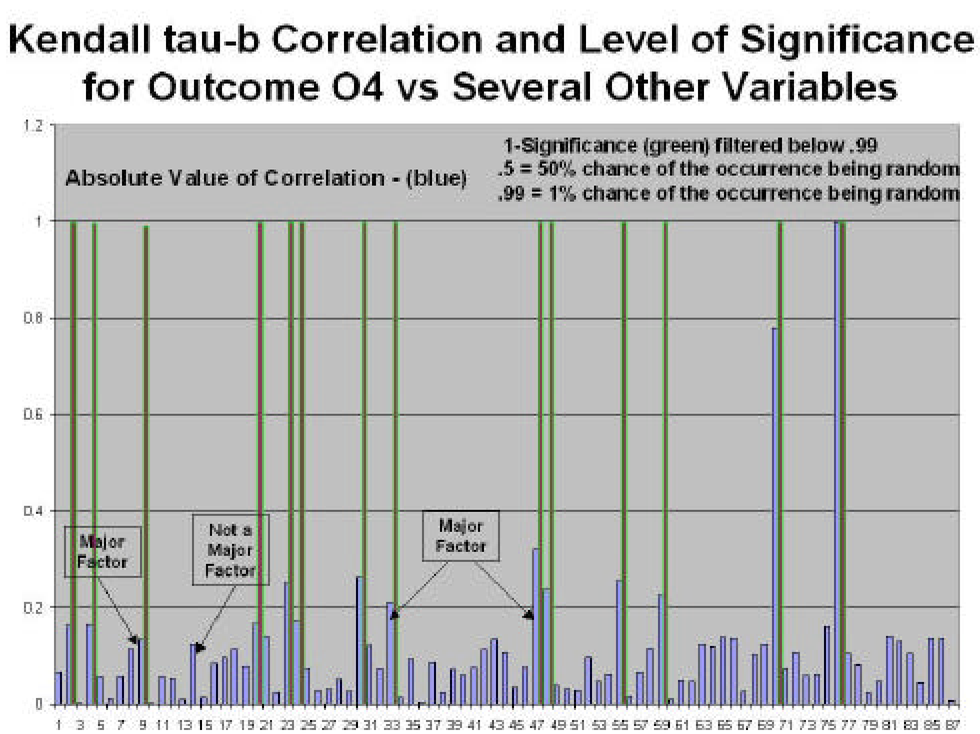


Figure 6-3. Identification of Major Factors

6.7 Best Practices

Once the major factors that influence outcomes are identified, the question of what to do to produce good outcomes and avoid bad outcomes remains. What environments do we need to create and what behaviors do we need to encourage to achieve effective technology transitions? We know that some projects have good outcomes. Based on experience with a large number of diverse projects the LeanTEC team identified "best practices" that produce good outcomes and documented examples of these practices.

The "best practices" and examples are intended to present concepts that will result in increased effectiveness of an average technology transition process. It is not an exhaustive set. Each company / business unit / project must implement the best practices and examples in a manner that produces the most benefit for that particular entity.

One might legitimately ask what qualifies the LeanTEC team to select best practices. The best practices given in Volume 3 of the manual are by no means and exhaustive set but they are representative of best practices applicable to the specific "big hitters" that are known to the LeanTEC team. Some qualifications indicating that the set of best practices is both reasonable and correct are shown below.

<u>Some Qualifications of the LeanTEC Team for Identifying Best Practices</u>

- Most core team members had 20+ years experience in the technology field
- Academic members were familiar with the latest theoretical developments
- Academic members had substantial industrial experience
- Academic / Consultant and Government members had independent and unbiased experience in a wide range of companies
- The LeanTEC team exchanged information freely and maintained confidentiality
- Team members had access to large numbers of current projects in diverse fields and from diverse divisions and locations (cultures) within a company
- All team members had access to diverse management perspectives
- Government members brought a combined government / industry perspective to both the project and management best practices
- Government members brought a knowledge of several complementary projects
- Government members provided customer insight on projects and processes
- The best practices and examples are the result of consensus among a diverse group of academics, industry and government professionals based on real life observations

For the survey data - correlation values of different variable classes can not be directly compared. For example, correlation values for team practices may show higher co-relations as a class with outcomes than the "when" or "barrier" questions. The relationships may be more direct for one than for the other. The co-relations, even when significant, do not define cause and effect. The relationship of one variable to an outcome may not be direct.

Example:

- "Frustrating Meetings" is Strongly Related (negatively) to "Transition to Product".
- This doesn't give much information on what to do.
- We look at what variables are related to "Frustrating Meetings"
- "Uncertain Funding" is positively correlated to "Frustrating Meetings"
- Does "Uncertain Funding" cause frustration, OR, do teams that have frustrating meetings also have trouble getting certain funding?
- Consensus of Professionals - the former is usually the case but in particular situations when the team has poor team practices this leads to trouble getting certain funding.

The Inference diagrams / tables such as those shown in Figure 6-4 can be used to aid in determining cause and effect relationships.

In All Instances Common Sense Must Prevail

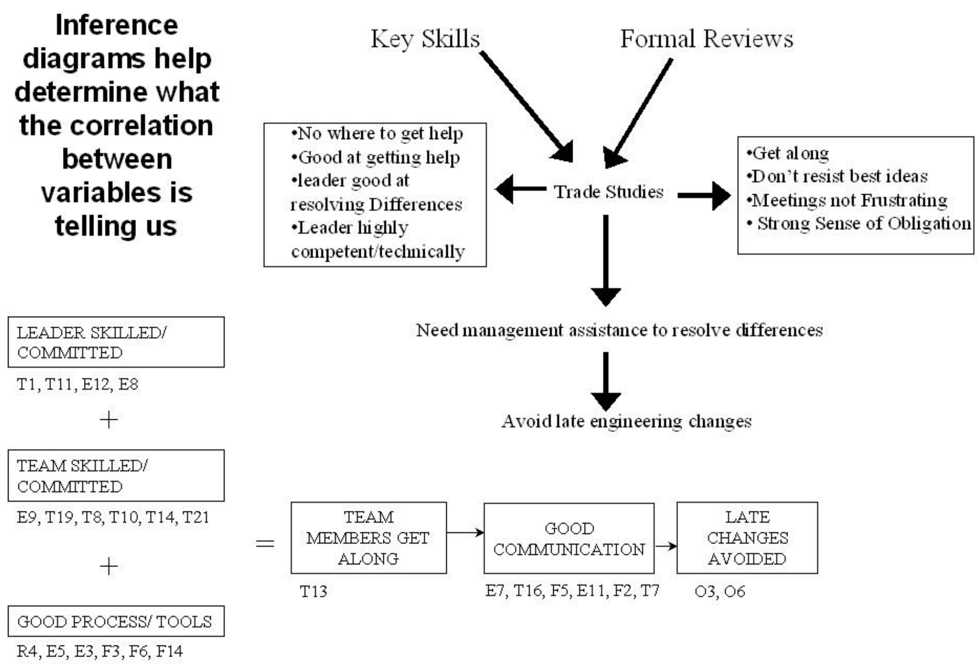


Figure 6-4. Sample Inference Diagrams

Once the major factors related to successful outcomes have been established using the methodology described above, one would like to obtain an estimate of the benefit from improved performance in a given area. The inference diagrams and experienced predictions of relationships among factors provided selection criteria for analyses of variables as related to outcome both singly and in various combinations. The results of these analyses are shown in Volumes 2 and 3 of the manual. Selected results are given in Section 14 of this report. An example of an examination of variables singly and in combination is shown in Figure 6-5.

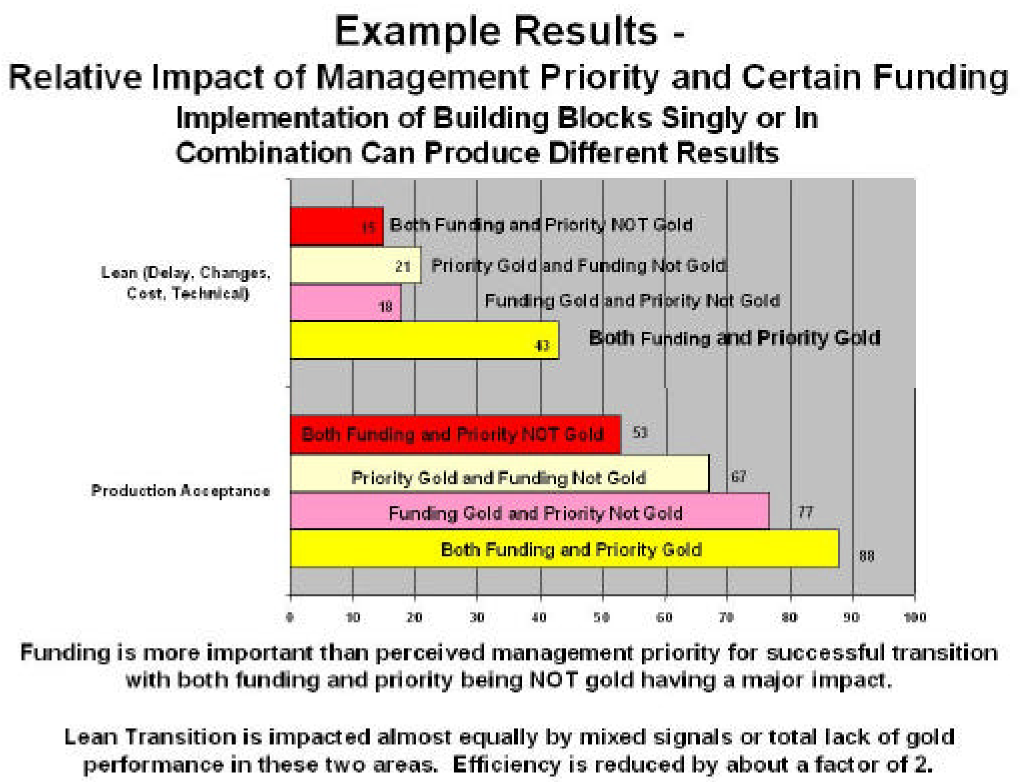


Figure 6-5. Example Results Looking at Single and Multiple Factors

6.8 In-Depth Project Analyses

As mentioned previously, in-depth analyses of specific projects were conducted at several stages of this program. In each instance a single project was studied either by formal or informal interviews in an attempt to understand the cause and effect relationships between specific variables and outcomes or the nature of the causality relationship among variables. For example, frustrating meetings had a strong negative correlation with some outcomes and also with other variables (positive or negative) such as certainty of funding. The in-depth study would attempt to determine if the frustrating meetings somehow led management to value the project less a so lower the certainty of funding or if uncertainty of funding for other reasons caused frustration among the team members. The results of such studies were used to help develop the solution elements.

In-depth analyses also were used to validate inferences made on the basis of worker input through management interviews. In some instances metrics were obtained to validate specific cases and provide results in terms of hard numbers for the general case. As part of the in-depth analyses, financial data and estimates of project metrics in terms of cost were obtained. The results of the financial analysis are presented in Section 14 of this report and Volume 4 of the manual.

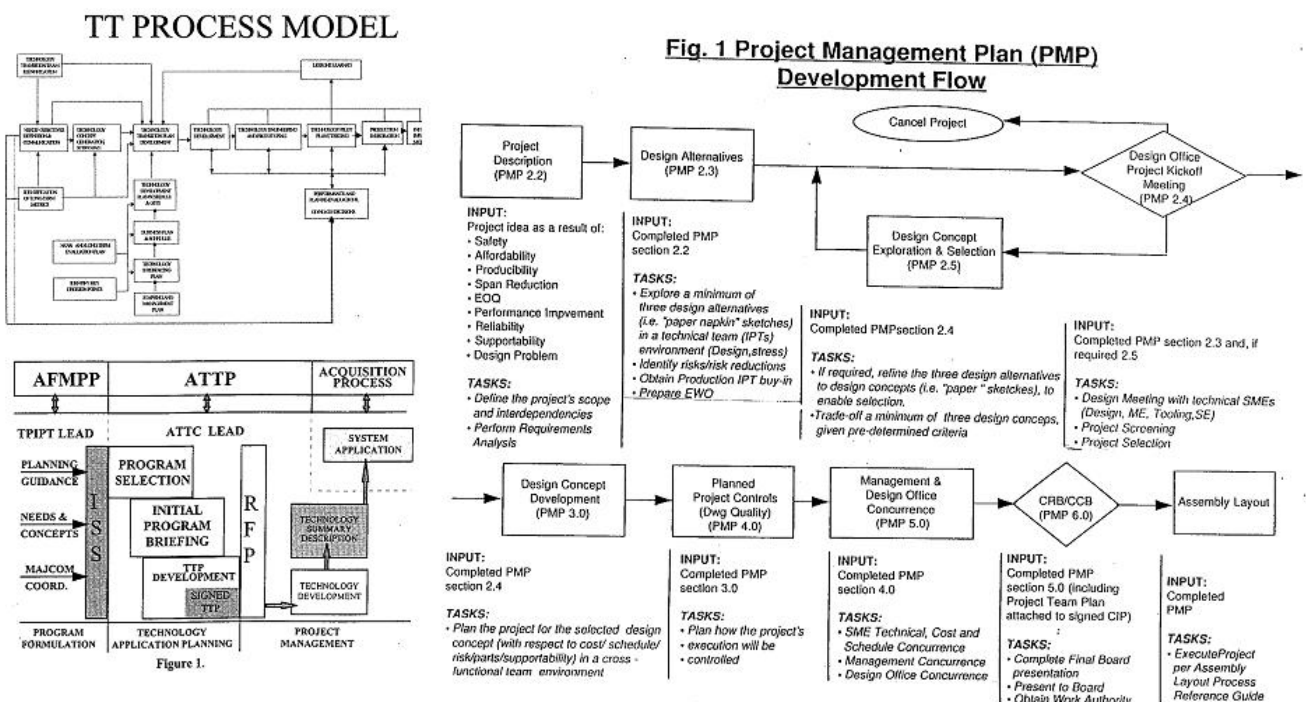
7.0 Task 4 - Describe the "As-Is" Process

An understanding of the current process for transitioning technology was to determine what improvements were necessary. Formal technology transition processes were not abundant in the literature, however several attempts to describe a current process (usually a flow chart) for

transferring technology were available. Internal company processes for technology transition were identified for various parts of the LeanTEC team member companies and those known to team members. The steps in the various processes were entered in a database. The common steps for most processes were defined as the official "As-Is" process. Figure 7-1 shows the processes that some companies think they have. In reality most of these are spaghetti charts.

The details of the processes were quite different and even at a fairly high level different nomenclature was used. The common process phases were Technology/Application Selection, Trade Study/Development, Prototype/Evaluation, Production Approval and Implementation. A team consensus was obtained on the time range for each of the phases. Additional insight into the time required for the various phases was obtained from project timelines that were completed as part of the project surveys. In-depth project interviews confirmed that "official" processes were seldom followed and that the actual process was often ad-hoc and had a flow diagram resembling a spaghetti chart. The overall "As-Is" process description used by the LeanTEC team is shown in Figure 7-2.

Example "As-Is" Processes



7-1. What Some Companies Think Their Process Looks Like

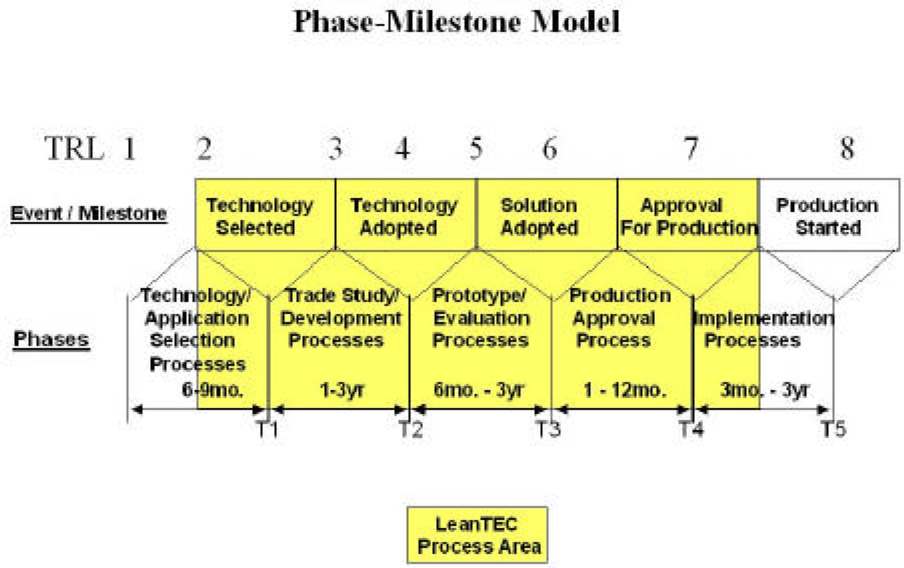
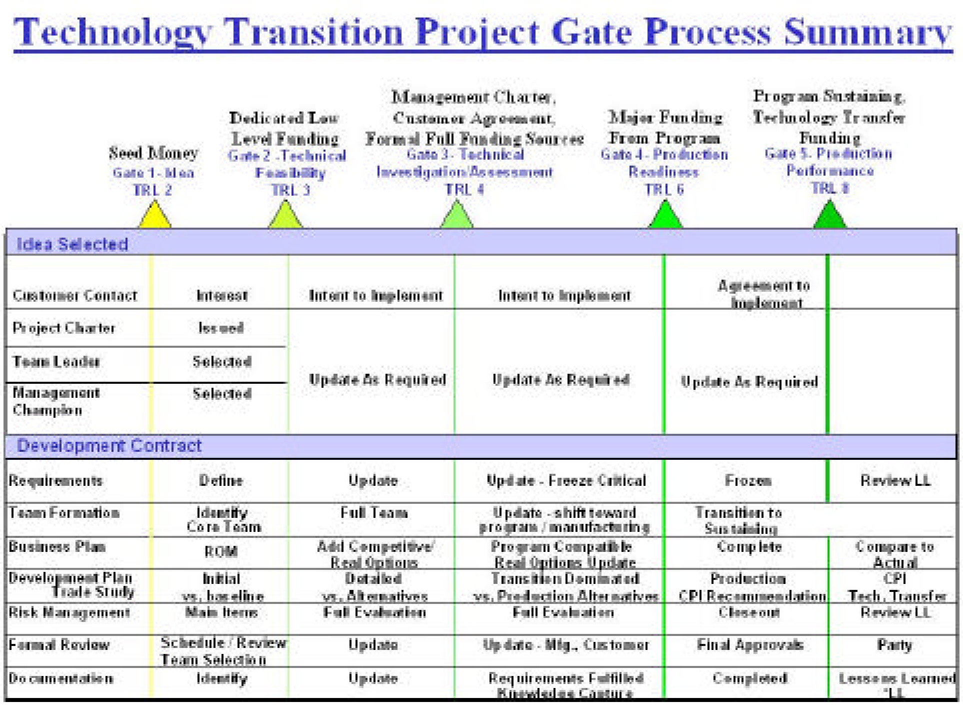


Figure 7-2. "As-Is" Process

It should be noted that the above process is sequential and could be shown as a flow diagram starting with the technology selection process and ending on the technology is implemented in production. In general, the sub processes in each process area are spaghetti charts. The value flow not only goes back and forth with and a given process area but often crosses process area boundaries returning to previous state. This "As-Is" process allows many management forms. This includes a phase gate process as shown in Figure 7-3.



Technology Transition Project Gate Process Summary

	Seed Money Gate 1 - Idea TRL 2	Dedicated Low Level Funding Gate 2 - Technical Feasibility TRL 3	Management Charter, Customer Agreement, Formal Full Funding Sources Gate 3 - Technical Investigation/Assessment TRL 4	Major Funding From Program Gate 4 - Production Readiness TRL 6	Program Sustaining, Technology Transfer Funding Gate 5 - Production Performance TRL 8
Idea Selected					
Customer Contact	Interest	Intent to Implement	Intent to Implement	Agreement to Implement	
Project Charter	Issued	Update As Required	Update As Required	Update As Required	
Team Leader	Selected				
Management Champion	Selected				
Development Contract					
Requirements	Define	Update	Update - Freeze Critical	Frozen	Review LL
Team Formation	Identify Core Team	Full Team	Update - shift toward program / manufacturing	Transition to Sustaining	
Business Plan	ROM	Add Competitive/ Real Options	Program Compatible Real Options Update	Complete	Compare to Actual
Development Plan Trade Study	Initial vs. baseline	Detailed vs. Alternatives	Transition Dominated vs. Production Alternatives	Production CPI Recommendation	CPI Tech. Transfer
Risk Management	Main Items	Full Evaluation	Full Evaluation	Closeout	Review LL
Formal Review	Schedule / Review Team Selection	Update	Update - Mfg., Customer	Final Approvals	Party
Documentation	Identify	Update	Requirements Fulfilled Knowledge Capture	Completed	Lessons Learned "LL

Figure 7-3. Elements of the "As-Is" and "To-Be" Processes in A Phase/Gate Process Form

The basic process elements shown in the “As-Is” process diagram also apply to the “To-Be” process. Thus Figure 7-3 not only represents the “As-Is” process but, with the application of Lean principles and best practices its represents the “To-Be” process. Important aspects of the “As-Is” process by the fact that from a portfolio perspective it is a batch and queue process, it forces a local rather than enterprise perspective and it does not show mechanism for either continuous improvement or continuous innovation.

Beyond describe being a process, one must identify what the characteristics are that make the process successful or unsuccessful. In the LeanTEC sense, the process is successful if it has the following characteristics or outcomes.

- The Right Technology Solutions Set / Product Application Is Selected.
- The Technology Either Successfully Transitions to Product or the Project Is Terminated for the Proper Cause at the Right Time.

<u>Those Technologies That Transition To Project Must:</u>

- Transition on Time
- Have Zero or Minimum Late Design Changes
- Meet Technical Goals
- Meet Cost Goals

The “To-Be” process must consistently produce these characteristics and outcomes.

8.0 Task 5 - Define the “To-Be” Process

As previously mentioned, the basic elements of the “To-Be” process are the same as those of the “As-Is” process. Major differences between the “As-Is” process and a “To-Be” process are the focus of a “To-Be” process on the implementation of best practices related to the major factors that produce desired outcomes, the application of Lean principles (specifically waste elimination, value flow, and mistake proofing), the cyclic nature of the process through the application of continuous process improvement and the enterprise view of technology transition.

The development of the final “To-Be” process by the LeanTEC team provides some lessons learned for implementation of technology transition processes in general. At one point in the LeanTEC program, 18 solution elements had been identified that fit in to the major sections of the “As-Is” process. Feedback from pilot projects and various briefings indicated that the description of the process needed to be simplified. One of the projectors of success from the project survey described in Section 6 was the ability to team to get outside help. At this point in time Raytheon became a member of a LeanTEC team. The new team member was able to view the existing good process with "new eyes" as mentioned in Section 1. The team exchange soon led to a new view of the construct of the process. The end result was the “To-Be” process described below and documented in the Manual for Effective Technology Transition Processes.

As shown in Figure 3-1 central aspect of this process is the key building blocks for success. These are the major factors obtained from benchmarking as described in Section 7. There are 72 building blocks identified in the current study. The implementation of these building blocks is accomplished by using best practices. There are 217 best practices that are related to the building blocks identified in this study. The link between the best practices and the building blocks are easily seen through the self-inventory attachment to Volume 2 other manual. In Volumes 2 and 3 of the manual the relationship among best practices, building blocks and solution elements shown. The eight solution elements are related to three steps of the cyclic process. The steps are enabled, planned, and execute. The cyclic nature of the process is driven by continuous improvement. This requires consistent methodologies for information flow and knowledge capture at all points of the process. The relationship among best practices, building blocks, solution elements and process steps are shown in Figure 8-1.

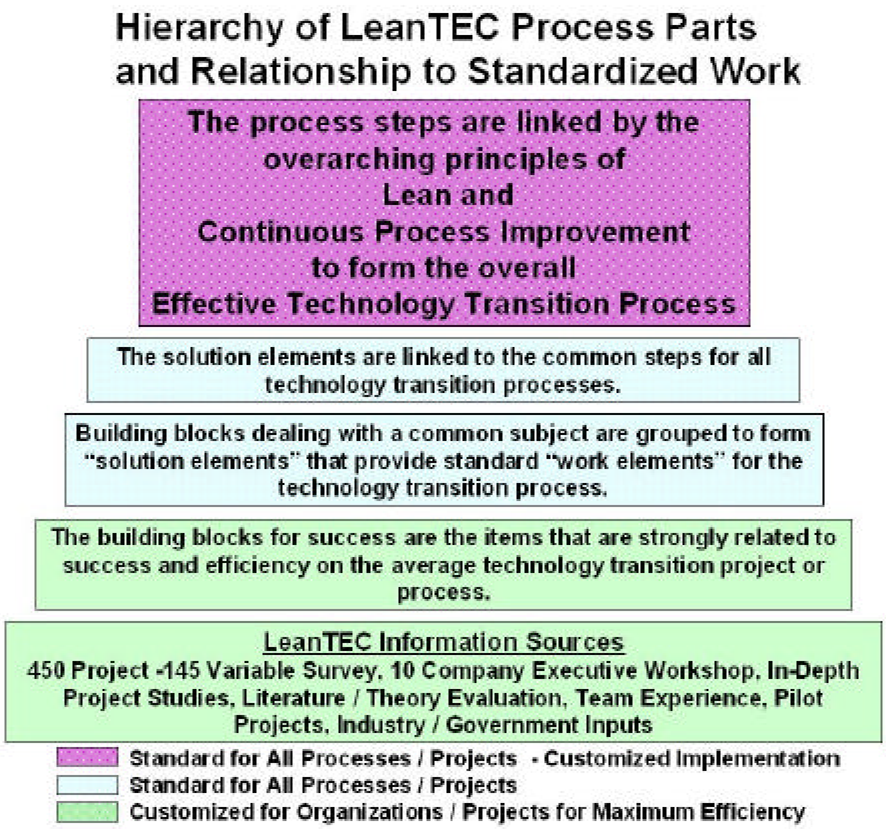


Figure 8-1. Relationship of LeanTEC Process Elements

8.1 The Lean Umbrella

The overarching principle of the "To-Be" process is the Lean umbrella. The concept of Lean applies to the process as a whole, and into every step and sub-step in the process. In addition to applying to the process in its parts, Lean principles are to be employed in the implementation of the "To-Be" process or the improvement of an existing technology transition process. Continuous process improvement is also to be done in a Lean manner. Simply put, Lean must be done Lean. In the application of the Lean umbrella, it is easy to let waste and bureaucracy eat up the gains that are being made from the application of the principles. The Lean umbrella is shown below in Figure 8-2.

Figure 8-2. The Lean Umbrella

The first item is to minimize waste. Every process has waste that needs to be eliminated or minimized. The companion item is effective relationships within the value stream. As with application of Lean principles and manufacturing facility, the first step is to do a value stream map and analysis of the existing process. LeanTEC recommends that this be done only to the level required to achieve major gains the first time through. Value stream mapping is not to become a project onto itself, consuming an inordinate amount of resources. More fidelity in the value stream map can be incorporated as a Lean process is applied several more times.

Once the value stream map is complete, the various process elements are classified as value added or non-value added. The non-value added elements are further classified as unnecessary or necessary. On necessary elements are to be eliminated and necessary waste is to be minimized with the eventual goal of elimination. In this process "value" must be defined for the various stakeholders. Value must reach the stakeholders by the straightest path and with minimum transaction costs in line with the goals of the enterprise. Details of the process are given in Volume 2, the Quick Start Guide, and volume for of the manual.

The concept of providing the right thing, at the right place, at the right time and in the right quantity is not only a statement of Lean principles, but also a statement of desired outcomes for technology transition. Providing the right thing deals with technology portfolios, project selection and strategic alignment. At the right place deals both with the technology transition process and the selected application for implementation of the results of the technology transition project. At the right time deals with strategic alignment (when the technology solution is needed for a given application and the strategic roadmap) and with the need for the technology project to transition on time with zero or minimum late engineering changes. In the right quantity addresses the concept of doing the number of projects that you can afford to do right in a portfolio and, at a project level, providing a technology solution that satisfies the customers needs but does not provide unwanted features.

The concept of optimal first delivered unit quality applies, at the process level, to the LeanTEC concept of mistake proofing the technology transition process. Much of the waste and unwanted outcomes that occur and current technology transition processes are due to trying to do the right things but not doing them in the right manner.

The LeanTEC best practices, key building blocks for success and solution elements seek to eliminated or minimize the mistakes that produce the bad outcomes. At the technology transition project level first-time quality should always be the goal for the technology solution being implemented. Applied consistently, this not only provides a good outcome for the specific project but also develops a culture that increases acceptance of technology solutions provided by the new technology transition process.

As with the technology transition process, Lean must become an ingrained part of the corporate culture applied to the entire enterprise and to each of its parts using an enterprise-wide view. The Lean exercise is applied to the technology transition process in each of its parts over and over to achieve ever greater gains and to eliminate waste and inefficient value flow pass that consistently creep into the process over time.

8.2 A Three-Step Cyclic Process Connected by Continuous Improvement

The basic "To-Be" process is made up of three steps - Enable, Plan and Execute. This process is shown below in Figure 8-3. The overarching connection of continuous process improvement (learning and improving), is shown as an integral part of the process.

Figure 8-3. A Three-Step Cyclic Process Connected by Continuous Improvement

Although the process is cyclic and thus has no beginning or end, for convenience we have designated "Enable" as step 1. Enabling is a beginning of a much improved technology transition process. The technology transition becomes a focused goal of the corporation and its business units. In this process step technology transition becomes more than an ad hoc assembly of processes generated by the creative juices of various people throughout the organization but with no central focus or link. Cultural environments that encourage behaviors that lead to good outcomes for technology transition are developed in this step. It is in this step that the strong link between corporate goals and strategies and the technology transition process takes place. The leadership role of achieving a balanced process that addresses both enterprise and local needs is stressed in the enabling process. Perhaps the statement that best describes this process step is balance and alignment.

In this step in both the culture and the details of the methodology for enterprise-wide and continuous process improvement are established. The mechanisms for efficiently collecting and disseminating data, information and knowledge (occasionally) are developed in this step and flowed down to the portfolio and project processes. The culture of taking lessons learned from the planning and execution steps, then reintroducing them into the overall technology transition process is accomplished in the enabling step. This is a key to keeping the cycle of improvement and innovation alive. It is this concept that makes this recipe for a technology transition process viable not only for 1996 or 2002 but for the foreseeable future.

The planning step links the overall corporate strategy for technology transition with the execution of specific technology transition projects that produce the final product. An analogy

can be made with running a race. We often start out strong and at the end get our second breath to finish fast, but failure to keep up the pace in the middle of the race often causes us to lose in the end. Planning is often considered a necessary evil. While it is necessary, it certainly is not evil. The planning ensures that we're doing the right thing by providing a portfolio of projects that link technology transitions to overall business units and corporate strategies. In other words, we plan to make sure that there is a customer for what is being done. Planning further allows us to define and described to others the method by which we plan to achieve the desired end. Once we have a stable plan, Lean principles can be applied to ensure that the method is efficient. During the planning phase projects are selected, resources are allocated, teams are formed an agreement is achieved among stakeholders. This last aspect is critical to effective technology transition. In the previous step and enabling culture was developed that provided incentives for technologists to develop technology and for customers, including production, to desire to accept the technology. However, once this culture is established good things just don't happen, they must be planned. Ensuring stakeholder acceptance (customers are stakeholders) is accomplished during team formation and the development of the team charter and plan/contract. The ultimate goal of the technology transition plan is to achieve stakeholder agreement that if the plan is successfully completed the stakeholders agree to transition the technology. The plan becomes a living document and the agreement subject to change by the stakeholders as circumstances require. A final aspect of the planning step is a development of specific methodologies required for knowledge capture at both the local and enterprise level.

Execution deals with "doing things right". Much of the execution stage is devoted to "people issues". They specific solution elements, building blocks and best practices given in LeanTEC manual provide tools for "mistake proofing" the execution of a technology transition plan with particular emphasis on barriers related to poorer social practices. These tools are based on experience provided by large number of projects and assume that, people being what they are, past behaviors predict future behaviors unless intervention occurs. We are sure that in the future new barriers associated with the behavior of people will be observed. The overall process mechanism provides for continuous improvement including the development of new tools and methodologies to deal with these behaviors.

Execution also involves determination of how the project is progressing. The execution of a collection and analysis of metrics, exchange of information, stakeholder feedback and decision-making reviews per the existing technology transition plan is provided for in this step. In the execution step constant checks are made to ensure alignment with strategies, goals and stakeholder needs as a currently exist. Changes to the plan are made as required by agreement of the affected parties. A major factor in the execution of the technology transition plan is efficient and accurate flow of information among stakeholders. The LeanTEC tool-set does not dwell on the technical aspects of the technology transition. In general, we do a good job (although seldom Lean) on the technical aspects of the problem. The technical problems do occur and will occur in the future. These problems can either be solved within the resource and time constraints of the project charter or they cannot. Effective stakeholder communication and related social processes will produce Lean outcomes through changes in the plan described above. Lean outcomes include not only successful transition but also timely termination of a project if that is required.

The execution step represents both the end and a beginning of the cyclic process. In this step the outcome is achieved. As we have done on the LeanTEC program, information from the enabling and planning steps can be related to the final outcome. This information capture feeds the enabling step by capturing lessons learned and using these to produce an improved set of processes procedures and tools ensures more effective technology transition for the future.

8.3 The Solution Elements

The solution elements and their relationship to the overall process is shown in Figure 3-1. That figure is repeated here as Figure 8.4 represents the "To-Be" process in its entirety.

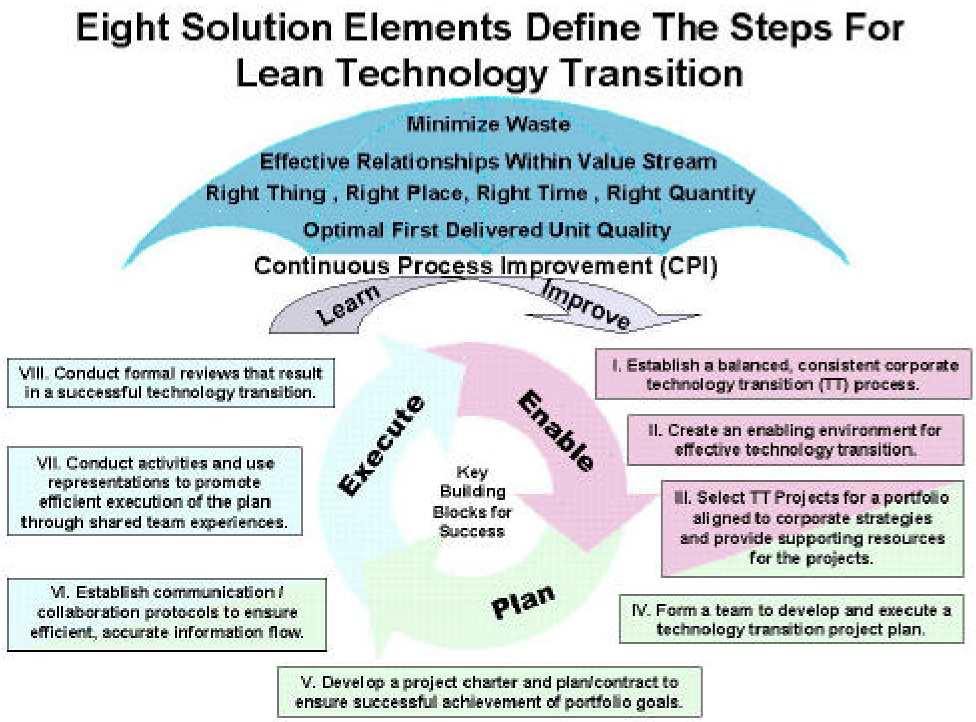


Figure 8-4. "To-Be" Technology Transition Process with Solution Elements Shown

<u>Solution Element I</u> provides for the establishment of the Lean technology transition process that is consistent throughout the enterprise. The concepts of standardized processes, strategic alignment, balance, Lean principles, consistency throughout the enterprise, knowledge capture and continuous process improvement are introduced as part of the solution element.

<u>Solution Element II</u> provides for the establishment of an enabling environment by making key principles a part of the enterprise-wide culture. Implied strategies that are often a part of corporate and business unit cultures must be specified to allow process control and improvement.

<u>Solution Element III</u> provides for the selection of technology projects in a manner that maximizes overall enterprise value. Central concepts in the solution element are strategic alignment and customer pull. This solution element also deals with the allocation of resources to projects and among projects.

Solution Element IV provides for formation of a cross-functional team to accomplish the portfolio goals at the project level. The critical issue of having all key skills on the team and having the team staffed by professionals or not over-committed is dealt with in this solution element. This solution element includes the specification of team design and decision-making protocols, which are often not formally stated.

Solution Element V provides for the development of a project plan / contract that provides response to the team charter and details steps required to achieve successful technology transition. This solution element provides shared activity that brings together all of the stakeholders with an interest in transition. The stakeholders range from those involved in the portfolio process to the end customer for the technology transition.

Solution Element VI provides for the establishment of protocols and methodologies to ensure efficient and accurate communication among all stakeholders and interested parties. Ensuring that each stakeholder has access to require information in a timely fashion and that the information provided is complete and accurate is necessary to a Lean process. This solution element also provides for the establishment of protocols for data (including metrics), information and knowledge capture consistent with the enterprise plan.

Solution Element VII provides for the selection and use of the activities required to successfully complete the technology transition plan. Emphasis is placed on including the "people" aspects of the activities as well as the technical aspects. The building blocks provide for activities that produce a "shared experience" that utilizes a cross-functional team to its fullest.

Solution Element VIII provides the review mechanism that is required to bring the technology transition project to a successful conclusion. As mentioned previously, the review process provides a mechanism for continuous improvement by capturing lessons learned and outcome metrics that feed the technology transition process design of Solution Element 1.

8.4 “To-Be” Process Details and Documentation and Implementation

The details of the “To-Be” process and its implementation are given in the Manual for Effective Technology Transition Processes. Volume 1 presents an overview, Volume 2 provides the details of the process design as well as an introduction to the solution elements and building blocks, Volume 3 provides the details of the building blocks and best practices required for implementation. The quick start implementation guide and attached "self inventory" provide a mechanism for rapidly initiating the implementation of the “To-Be” process in areas of prime importance to the specific company or business unit. Further details concerning the building blocks are presented in Section 14 of this report.

An important lesson learned from the pilot projects, briefings and experiences with the application of Lean principles was a necessity of systematic, enterprise-wide implementation and incorporation of the process into the culture to achieve breakthrough results. Moving waste from process step to process step or improving value flow locally at the expense of downstream process steps does not benefit the overall enterprise. Local application of specific solutions and best practices will provide some local benefit. However, the true benefit comes from systemic application.

9.0 Task 6 - Develop and Submit Phase II Plan

Development and submittal of the LeanTEC Phase II Plan was formally completed in March 2000. The plan consisted of a detailed description, schedule and spending profile of activities planned for the duration of the program (Tasks 6 – 10).

A major focus of Phase II was demonstrating the effectiveness of the LeanTEC solutions including the Formulation of Experiments (Task 7) and Conducting Experiments (Task 8). These are discussed in detail in Sections 10.0 and 11.0 of this document. Tasks 9 and 10 defined the data analysis and information dissemination efforts. They were added to provide a clear breakout of activities for planning and tracking purposes and did not increase the work scope nor the cost to the program.

Continued Data Analysis (Task 9) had three primary activities and goals for continued investment in analysis: collecting, cleaning and analyzing results for the experimental program; benchmarking company performance to fulfill commitments to new and existing company participants; and extending analysis of the current and expanded data set. This was done through supplemental project surveys, in-depth data and analysis, experiment feedback and barrier / enabler updates.

Communications (Task 10) was another major focus of Phase II and included the dissemination of LeanTEC results. The main medium for disseminating LeanTEC results is the “LeanTEC Manual for Effective Technology Transition Processes". Many other activities were linked to updating the Manual. The information contained in the Manual was the basis for the experiments, and interim and final experimental results guided Manual updates and enhancements to make the Manual a more useful tool. The communication and dissemination activities are discussed in Section 13.0.

The Phase II Plan applied LeanTEC principles by providing a standard framework while maintaining the necessary flexibility to respond to new information from surveys, analyses, experiments, and customer and user inputs.

10.0 Task 7 - Formulate Experiments

The plan for selecting and implementing pilot projects to serve as experiments in the application of the "To-Be" process to demonstrate the benefits of the implementation of LeanTEC tools (solution elements) and to obtain feedback from the experiments to update those tools was the focus of this task. The plan formulated included the general design of the experiments and underlying philosophy, the selection of specific projects as likely LeanTEC pilots and the plan for monitoring and obtaining data for selected metrics.

10.1 Experiment Design

Control, paired, and unpaired pilot projects were targeted for evaluation. The control group monitoring was represented as a benchmarking activity. The intent was to match pilot projects that employed the LeanTEC principles at least in part with those that did not employ any LeanTEC principles. A careful examination of potential control projects showed that it was unlikely that more than one or two projects could be found that were not contaminated or likely to become contaminated by projects applying the LeanTEC principles either through LeanTEC intervention or by other initiatives that came to similar conclusions. The controls for the pilot projects then became the consensus values for the "As-Is" process and the data from the survey timeline for similar projects.

The purpose of using both experiments and controls was to determine if, and to what extent, the use of the full LeanTEC tool set is the reason for the differences in results from the two groups. These differences cannot be linked to a single LeanTEC tool for this group, only to the total package of the tools implemented during the experiment.

The overall flow of the LeanTEC pilot project experiment implementation is depicted in Figure 10-1. The initial findings which were based on the preliminary list of barriers and enablers (Section 5.0) developed from the initial project surveys, and on benchmark data obtained at an executive workshop with R&D executives from major companies (Section 6.0), were compiled into early versions of the LeanTEC manual. These findings were presented in management briefings. Feedback from these briefings resulted in a list of candidate pilot projects.

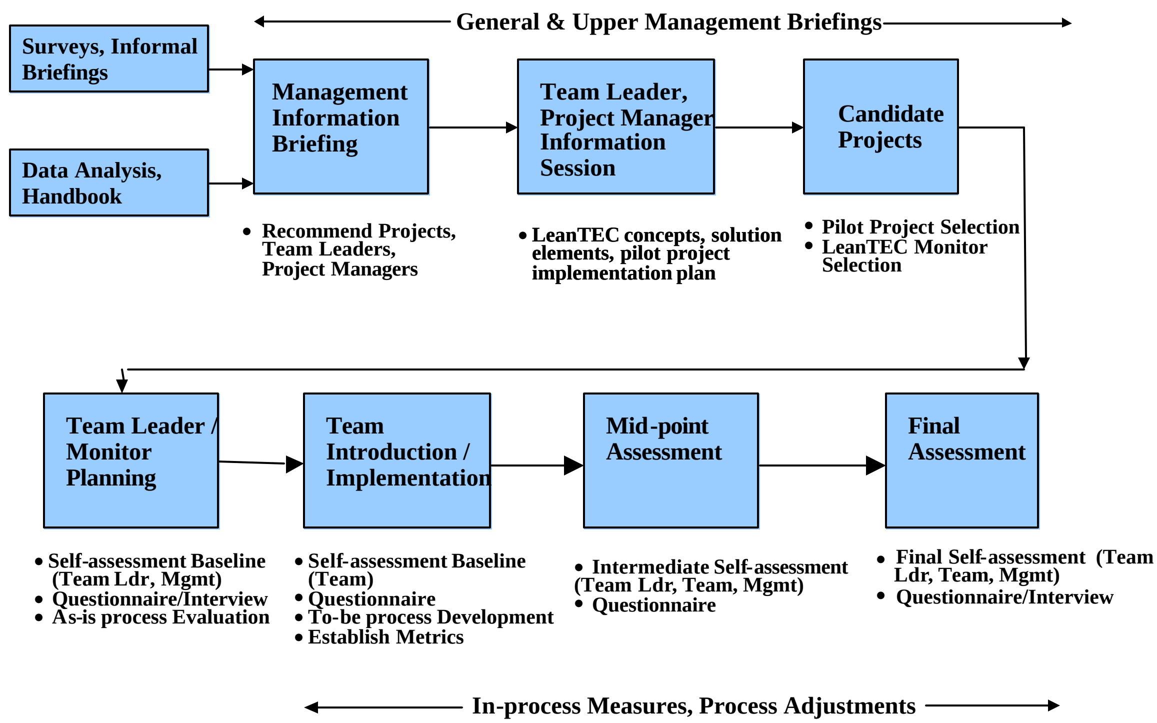


Figure 10-1. LeanTEC Pilot Project Implementation Flow

10.2 Project Selection

The projects considered for selection were drawn from structures (both metals and composites), and from manufacturing technology. The primary reason is that these two areas were the original focus of this LeanTEC program and represent hardware and manufacturing process emphases. These organizations had already made the decision to move toward adoption and implementation of many of the LeanTEC solution elements for all of their projects, so implementation of LeanTEC elements on specific projects should have required little added effort. Since most LeanTEC personnel reside in these organizations, selecting projects from within also should have simplified the processes of obtaining management approval, training, and monitoring.

The project selections were finalized by: 1) obtaining approvals from management in the affected organizations to use specific projects as experiments and controls, 2) completing the schedule for implementing training for experiments, and 3) beginning the assessment and monitoring of experiments and controls.

If an experiment was cancelled, a replacement project was selected when possible. The same training, self-assessments, monitoring, etc. as described in previous sections were performed for any replacement projects.

10.3 Training / Pilot Project Implementation

For the experiments, the project team leaders were trained in use of the LeanTEC tools, and their progress and results toward completion of the project over the time span of the experiment (approximately one year), was regularly monitored. A consistent training document and suggested set of strawman metrics was used by all LeanTEC monitors. These monitors also participated in the development of the training materials and in feeding back lessons learned from various implementations resulting in major restructuring of the LeanTEC solution elements and implementation manual. The team had almost no impact on the technology transition process design, portfolio issues / project selection or cultural aspects. There were a limited number of items from the then 18 solution elements that could be controlled by the team. Emphasis was placed on this subset of the total LeanTEC solution set that was to be considered for implementation by the team. It was the intent of the experiment to evaluate the impact of this "vitamin pill" of solutions on outcomes of the projects.

A LeanTEC core team member or trainee was assigned to each project as a monitor for the purpose of providing guidance and assistance to the team and to insure proper monitoring and information gathering. The training for the project team and associated management focused on the practicality and benefits of each of the solution elements rather than on the underlying theory or data findings. The project team or leader designed the implementation with guidance from the LeanTEC monitor. The LeanTEC solution elements were implemented using past team progress, not starting over. The project teams maintained control of the projects and implemented solutions that were anticipated to provide benefit.

The monitors collected data on the team processes, behaviors and progress through questionnaires, interviews and direct observation. The guiding principle was that application of the LeanTEC principles would not take much more time than what was currently being spent and would more than make up for any additional time spent up front with reduced overall cycle time. The team leader and team were free to reject any LeanTEC procedure that they considered waste or counter-productive on their specific project.

The solution elements that could be influenced during the training and monitoring of the project teams were identified. They are listed below and an example of a pilot-project-solution-element implementation plan is shown in Figure 10-2.

- Process model to fit the project and identify process risks
- Lean concepts and value stream analysis
- Creating a project charter
- Cross-functional team design
- Creating a project contract/plan
- Communications and collocation
- Shared communications objects
- Focused team activities – trade studies
- Performance metrics
- Management reviews

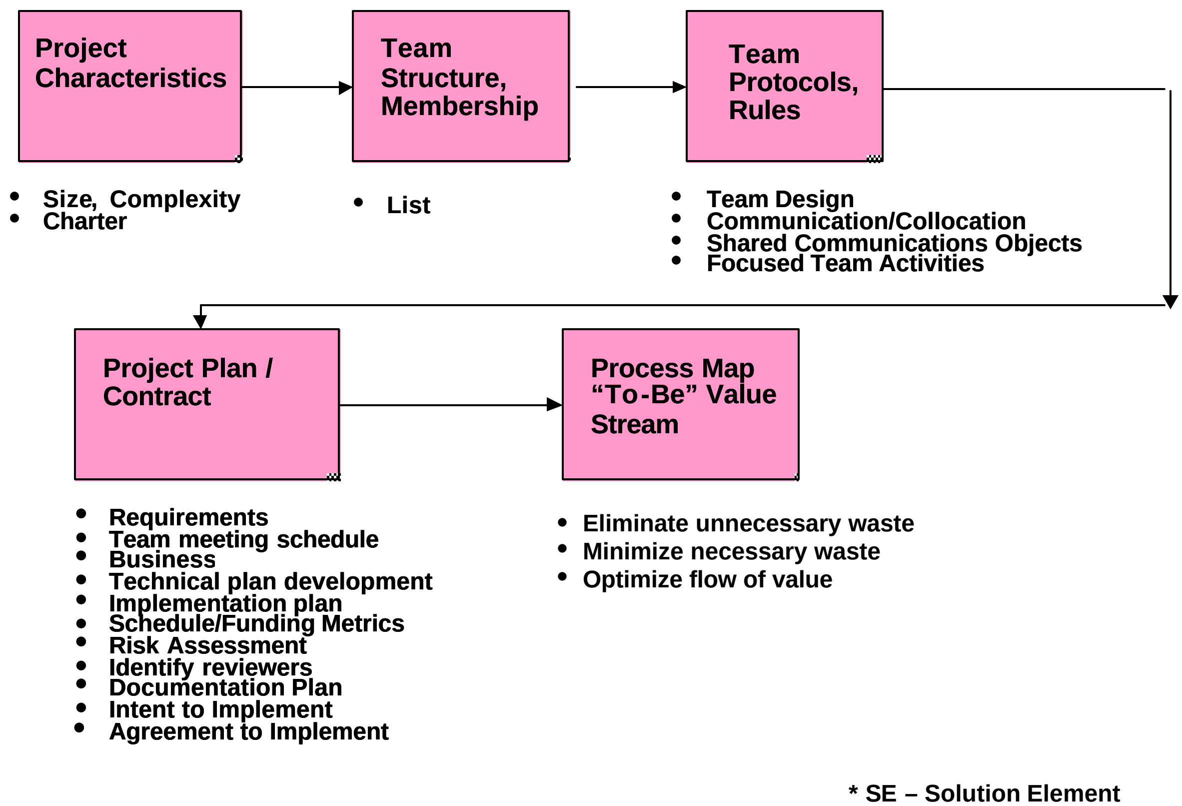


Figure 10-2. Example of a Pilot Project LeanTEC Implementation Plan

The other solution elements, which were not part of the intervention or implementation of the LeanTEC tool set, were monitored only. It should be noted that the original solution elements that were the basis for the experiment design were revised into the current format based on feedback from initial monitor training sessions and pilot project implementation activities.

10.4 Monitor Progress

It was very important that the teams worked toward their goals of technology transition during the experiment period with a minimum of interruption and hindrance. Accordingly, the frequency and depth of monitoring of all projects were selected to minimize the time required from team leaders, team members and management, while still providing the necessary amount and types of information for the subsequent analysis of results to be valid. A summary of the LeanTEC pilot project monitoring and intervention plan is shown in Figure 10-3.

LeanTEC Pilot Projects
Monitoring & Intervention Summary

	Assessment	Objective	Instruments
Baseline	• Project Leader & Selected Team Members • Management • Business Mgt.	• Determine current TRL (Technology Readiness Level) • Determine current level for Solution Elements (Gold, Silver, Bronze) • Project cycle time, cost etc.	• Interview & discussion • Manual self- assessment • Questionnaire (30 minutes)
In-process	• Project Leader & Selected Team Members • Management • Accounting	• Observe application of Solution Elements • Document observations • Provide assistance as-needed • Labor - Cost - Earned Value Data	• Checklist completed by Monitor at Team mtg (2 per Mo., 20 minutes each) • Checklist completed by Monitor at formal reviews (10 minutes each) • Questionnaire (10 minutes / 60 days) • Interview / Discussion / Questionnaire (30min) - Team & Management (at mid-point)
Final	• Project Leader & Selected Team Members • Management • Business Mgt.	• Determine new level for Solution Elements (Gold, Silver, Bronze) • Assess actual cycle time, cost etc.	• Manual self- assessment • Interview & Detailed Discussion with Team & Management) • Questionnaire (30 minutes.)

Figure 10-3. LeanTEC Pilot Projects Monitor & Intervention Summary

The pilot projects were observed at regular intervals with additional in-process data collected. The purpose of monitoring was to establish, in quantitative measures, the absolute and relative progress of the teams in each of several important metrics, bulleted as follows:

- Transition success (rate of transition, % of technologies transitioned)
- Cycle time (Speed of transition, span/lead time in months)
- Accomplishment of transition project technical and cost goals
- Efficiency of transition (minimizing changes as technology moves into production)
- Breadth of transition (transfer to multiple programs)
- Minimization of non-value added tasks and maximization of value flow (leanness of process)

Major evaluations were done at the start, around the midpoint of the experiment and at the end of the experiment when possible. These did not usually coincide with the start, midpoint and end or the project. In process measurements taken at the experimental points were used to project expected outcomes. During baseline data gathering, the project leaders and selected

team members completed initial and in-process self-assessments. The LeanTEC monitor participated in the pilot project team meetings, collected the data and worked with the team leader to implement the appropriate solution elements.

10.5 Metrics

Baseline Metrics. Both a project evaluation sheet and a self-assessment for the various solution elements were documented at the start of the implementation. The project evaluation was used to capture data similar to that captured in Part 1 of the LeanTEC survey questionnaire. This not only provided baseline data for the current project, but linked it to the survey data providing an industry baseline. The self-assessment determined the projects' status on specific solution elements based on poor, average, and best practice categories (bronze, silver and gold) from an industry perspective. An example self-assessment form is shown is Figure 10-4. This self-assessment data was taken at the start and end of the experiment. A team roster was also obtained at the start of the project to monitor turn over and other staffing issues.

Solution Element 6

Lean Concepts and Value Stream Analysis

Self-Assessment: How does your organization's application of lean concepts to technology transition projects rank on this capability scale?

Capability Level	Strongly Agree	Agree	Neither Agree Nor Disagree	Disagree	Strongly Disagree	Don't Know
Management and staff are trained in Lean concepts.						
The application of Lean is a part of the corporate culture.						
Lean concepts are used to maximize value and value flow to customers and to the business unit.						
The value of people is recognized and respected.						
Minimization or elimination of non-value added tasks is embraced and encouraged by management at all levels.						
Lean concepts are applied to TT processes.						
Systemic rather than local solutions are sought.						
The effort used in applying Lean principles is commensurate with the expected benefits.						
Continuous improvement is encouraged and enabled.						
The TT process is recognized as dynamic and requiring constant application of Lean thinking.						
Lean is used in conjunction with other theories and methods where it is adds value to the process.						

How do you rate the project overall with respect to this solution element? Please Circle.

- - - - - - - - -

Poor Average Excellent

Figure 10-4. Sample Original Solution Element Self Assessment Form

Data Acquisition Methodology. Three types of metrics were used to evaluate the benefits of LeanTEC solution element implementation: 1) "Accounting" data was hard data obtained through independent measurement. An example of this type of data is the number or projects worked on by key members of the team from the name labor records. Another is the cost and savings data obtained from accounting. 2) Survey and Observational data required some interpretation on the part of the person being surveyed or the observer. The attempt was made to keep this data consistent throughout the experiment (same questions or observations and

same respondents and observers) as much as possible. 3) The third type of data is anecdotal. This data contains much information but is more subjective in nature than the others. This data consists of opinions (project team, management and LeanTEC observer) and was documented throughout the program.

In-Process Assessments. Checklists and success probability assessments were completed as in-process checks throughout the experiment period.

Team Meetings: The LeanTEC monitor participated in experiment project team meetings on approximately a bi-monthly basis. Any in-process assessments were also done at this time. The monitor attended all formal meetings (e.g. reviews by management), of all project teams. The monitor then discussed ways the team could work toward the gold levels in each of the solution elements, emphasizing those in which the team's shortfall seemed most pronounced. The monitor completed an event monitoring form from these meetings (Figure 10-5).

PP# | Proj:		Type of Event: Date:
Item		**Comment / Observation [no entry = no change]**
Attendance		
	1	**Members Present:**
	2	**Members Absent:**
Area Observed		
- Progress	**3**	**Milestones / Actions Met/Missed/Late:**
	4	**Discoveries / new facts:**
	5	**Problems / issues:**
	6	**Errors / miscommunications:**
	7	**Successes / failures:**
- Changes		
	8	**Roster:**
	9	**Cost / Tech / Sched Risk:**
	10	**Budget/priority/funding:**
- SE Implementation		
	11	**Trade Studies / Focused Activities:**
	12	**Use of Physical Representations:**
	13	**Charter:**
	14	**Contract:**
	15	**Communications:** **- errors / miscommunications** **- participation in this event by members**
	16	**Key skill availability:**
	17	**Performance metrics reviewed:**
	18	**Management help / resolution needed:**
	19	**Lean concepts / value stream:**

Figure 10-5. Pilot Project Event Monitoring Form

11. 0 Task 8 - Conduct Experiments

Pilot project team leaders received initial training in the use of the LeanTEC toolset - including an introduction to the LeanTEC Manual. Then their efforts were actively monitored and supported by LeanTEC personnel who helped the teams employ those tools to their fullest extent, recognizing that some tools, such as the use of trade studies, might be less appropriate for some projects.

During the course of the experiment, team leaders, team members, management and customers were encouraged to express their opinions on the LeanTEC solution elements and the specific project's progress to the LeanTEC team representative. These were documented and reported to the LeanTEC team and the Manual sub-team during normal team meetings or during the normal cycle for Manual release. Many of the observations resulted in changes to the experimental plan and / or Manual. This information is documented in Volume 4 of the final manual release attached to the final report.

11.1 Experiment Results

A summary of the results from each of the 20 LeanTEC pilot projects is shown in Figure 11-1.

PP #	Description	LeanTEC SE, Bldg Block Discussion	Status/Outcome	Conclusions
1	Complex project, 3 disparate groups, technology used in other area	Initially gold on cross-functional team, physical representations elements. Silver on all others. Mid-point indicated lean concepts, focused team activities improved to gold, physical reps stayed gold, project plan & collab. environment stayed silver but lower on scale. Project charter, cross-funct. team, and perf. metrics dropped to bronze. Final assess. stayed about the same with cross-funct team improving to silver, project plan and mgmt reviews dropping to bronze, focused team activities moving from gold to bronze.	Project **active** at end of monitoring effort. Probability of meeting technical and cost goals 80%.	Initial assessment completed just after team's efforts were redirected from one charter to another. Communication and decision making protocols lacking and project plan elements missing even though team leader received LeanTEC training. Potential for non-lean outcomes is high.
2	Multi-year, multi-organization project, very small team (Team Ldr plus one part time person),	No LeanTEC solution elements implemented.	Project management strategy/priority changes reduced Team Ldr effort. **Inactive** as pilot project	Not a management priority, no longer aligned with strategy.
3	Moderately difficult technically, applies to many programs	Poor staffing, uncertain funding, no mgmt champion, not a mgmt priority. Temporary Team Ldr change left project virtually inactive for a period of time. No LeanTEC solution elements implemented. Mgmt decided to eliminate budget.	Project **cancelled** approx. 6 months into monitoring.	Not a management priority, no longer aligned with strategy.
4	Involved breakthrough technology widely applicable, subcontractor employees comprised team	Initial briefing on LeanTEC concepts generated great interest, however, attempts to further discuss/implement solution elements were not responded to.	**Inactive** as pilot project	Not a mgmt priority and "no time" suspected
5	Application of relatively new technology to relatively minor type of product, collaboration between team and subcontractor		Effort ongoing and technical success is probable but team activity will not be utilized. **Inactive** as pilot project	Management strategy change suspected.
6	Technically complex. Project's purpose changed mid pilot project time period, minimal activity initially, increasing slightly.	Silver on Project charter and focused team activities elements. Bronze on others. Communications and decision protocols implemented.	Active, progressing well	
7	Application of high risk technical approach	Poor staffing, not a management priority noted.	Some activity continuing with Team Ldr. **Inactive** as pilot project because of excessive delays in team formation	Management champion and/or clear charter needed
8	Moderately difficult technically, applies to many programs. Small team (two members) working part time on project.	Project ongoing 6-8 months at start of LeanTEC monitoring, tech. readiness level of 7, low schedule and cost risk. Initially assessed as mid-silver on all solution elements. All key skills on team and stakeholder identification noted as lacking.	Timely termination, **Lean outcome achieved**	Change in company strategy, declining market

PP #	Description	LeanTEC SE, Bldg Block Discussion	Status/Outcome	Conclusions
9	Automated syststem for aircraft structure. Primary application to one product, broad secondary technology transfer	Team Ldr training and interview conducted	Lack of team leader response, **Inactive** as pilot project	
10	Precision assembly technology. Primary and broad secondary applications. Larger team (12-15 members)	Cross-functional team w/all key skills represented and some core members full time (gold). Team Ldr trained in LeanTEC methods, most team based solution elements/building blocks in place or implemented. Lean concepts, value stream analysis only elements rated bronze.	Implemented primary application, terminated 2nd applications (cost constraints, low ROI, other option identified). **Lean outcomes achieved**	
11	Medium complexity advanced assembly systems project, medium size team (5 members)	Team Ldr trained in LeanTEC methods, and interviewed	Lack of team leader response, **Inactive** as pilot project	
12	Medium to high complexity advanced assembly technology, primary and secondary applications, small team	Team Ldr changed multiple times, team structure, communication protocols, project plan need improvement (silver). Project charter, lean concepts, performance metrics bronze.	**Inactive** as pilot project.	Team Ldr spread across many tasks, unable to implement LeanTEC concepts
13	Moderate complexity advanced assembly technology, primary and secondary applications, large, widely distributed team	Well staffed team (silver), many LeanTEC solution elements/building blocks partially or improperly implemented, mgmt champion not committed, stringent technical requirements causing delays. Project contract/plan performance metrics, physical representations, collaborative environment less than adequate (bronze)	Unexpected delays, original target and cost savings goals will not be met, project ongoing, **non-lean outcomes** to date	Cultural barriers and resistance impacting technology transition, Team Ldr reluctant to embrace appropriate LeanTEC implementation
14	Adv. Assembly tool/methodology dev., medium to high complexity, primary and secondary applications, medium core team (5 members)	Gold on project charter, collaborative environment, phys. representations. Silver on mgmt reviews, portfolio selection, mgmt, & planning resources, cross-functional team. Bronze on project plan, focused team activities, performance metrics, lean concepts	Team Ldr changed, 50% probability of meeting cost goal, 80% prob of meeting technology goals, 60% prob of accept by customer, milestone schedules slipping-**non-lean outcomes** to date	
15	Complex project, multiple target applications	Much cultural resistance, no mgmt champion, communications protocols violated, all stakeholders and initial application not identified, funding uncertain. Attempts made at focused team activities, selecting a mgmt champion, identifying all stakeholders.	Project status improved-mainly due to Team Ldr's efforts. Partially transitioned. Delays incurred. Tech.& cost savings goals achieved.	
16	Complex project, technology has wide range of applications, large cross functional team	Communication problems and turf issues between functions, some cultural resistance, Poor initial definition/charter, difficult getting all key skills and stakeholders involved ("no time") - bronze. LeanTEC concepts implemented.	Project definition/scope, communication improved. Project ongoing, intermediate cost and technology goals met.	Mgmt support there but still bronze on committed mgmt. champion. Other elements improved to silver
17	Highly complex technology, large technically diverse widely distributed team, stringent customer and stakeholder requirements.	Gold on project charter and phys. representations. Silver on cross-functional team, lean concepts, project plan, collaborative environment, and focused team activities. Bronze on formal mgmt reviews	Transition in process (multi-phased, some phases complete). Some milestone slippage. High probabilities of success remain (90-100%) **Lean outcomes** being achieved.	Excellent participation and commitment by core team members contibuted to success. Strong support from senior mgmt and clearly defined needs of stakeholders.
18	Highly complex technology, large widely distributed team.	Overall silver on solution elements from start of monitoring. During monitoring key skills were not always available. Focused, scheduled "tiger team" meetings were used extensively. Stakeholder analysis recommended by monitor and completed.	Transition in process. High probability of meeting or exceeding technical and cost goals. **Lean outcomes** being achieved.	Effective program manager, less than effective mgmt champion. Physical representations played key role. Two major design changes during development.
19	Medium complexity hardware and software development project. One application.	Project is a mgmt priority with many "best practices" in place. Gold on physical representations, high silver on focused team activities, project charter & plan, lean concepts and metrics. Stakeholder analysis completed.	Project on schedule with high probability of technical goals being met as of end of LeanTEC monitoring period.	
20	Moderately complex project, many target applications. Replacement project in early 2001.	Silver on most solution elements, gold on focused team activities. Team roster, team design in place. Little response from team leader on LeanTEC participation.	Ongoing project. Good status technically.	Possible staffing and mgmt priority issues.

Figure 11-1. Experimental Results by Pilot Project

Note that no team was able to fully implement the entire “vitamin pill” of solutions during the course of the experiment. Therefore, the results are somewhat dependant on the type, number, and extent of solution element implementation.

Data and information was collected on each of the projects using the self-assessment tool and estimates of success probability form. The data is not adequate to conduct a formal statistical analysis and obtain statistically significant results. Several projects were terminated prior to completing the LeanTEC information forms. In general these projects were terminated with justification and in a timely manner. These Lean Outcomes are indicated above. As predicted by LeanTEC, staffing issues were a major factor in the experiments. Some of the terminated projects were casualties of turnover or difficulty in finding the right leader. The LeanTEC emphasis on doing only what you can afford to do right contributed to many of the Lean terminations. This outcome was not anticipated and constructs to capture this information in a statistically meaningful way were not in place. The over-commitment of team leaders and core team members made it difficult to collect the final LeanTEC information sheets. They had applied the selected LeanTEC principles, obtained the benefit and were busy with the business of the project. Filling out the experimental forms was not seen as value added or Lean (lack of enterprise perspective). The data that was obtained is summarized in Volume 4 of the manual.

Although the data / information was not sufficient to do the desired statistical analysis it did indicate definite trends. In addition, interviews with the team leaders as well as the observations of the LeanTEC observers at various meetings provided a wealth of anecdotal information. This information was very valuable in structuring the final version of the Manual for Effective Technology Transition Processes.

11.2 Conclusion / Lessons Learned

Implementation of LeanTEC concepts requires full acceptance and support from all levels of personnel. LeanTEC monitors met with resistance and hesitancy from team leaders that certainly impacted the degree to which concepts could be applied and data could be captured. The resistance most likely is due to the barriers to successful technology transition that LeanTEC addresses (e.g. uncertain or inadequate funding, improper staffing levels, etc.). From the perspective of the LeanTEC pilot projects and experiment period this impacted the continuity, consistency and availability of data for collection and evaluation.

Other lessons learned include:

- Initial structure and quantity of LeanTEC solution elements was overwhelming to train teams on and to implement. This feedback resulted in reducing quantity of solution elements from 18 to 8 by combining categories and developing a building block approach.
- Perception of additional time and effort to improve processes hindered acceptance and implementation.
- Difficulty in getting timely, honest assessments of the project due to fear of how assessment will be used

- Large and distributed project teams require significantly more time to implement solutions and to monitor.
- Reluctance of project managers/team leaders to “jump in” to LeanTEC solutions after initial enthusiasm
  - Streamlining the self-assessment and monitoring approach could help
  - More visible middle and upper management support (cultural change) is needed

- Team Leaders are often the technical “inventor” or “expert” and not necessarily the best project manager hence poor management practices and little importance placed on improving them.

- Small projects (4 people or less) seem a lot more likely to have problems
  - Typically under funded and under staffed to start with – then cuts are made
  - Typically working on low-TRL-level technology applications – large uncertainty about whether their technical efforts will hit a wall; large uncertainty in identifying customers and savings
  - Efforts are sporadic since Team Leaders and Team Members are rarely full time – the “squeaky wheel" philosophy applies

- Adopting a subcontractor team is problematical: no “hammer” to obtain their cooperation, and PP-related efforts – uncompensated – are easy to drop when budgets / schedules get tight

- Uncertainty of funding, the threat of budget cuts or termination, hangs over all projects, even Pilot Projects.

The main predictors of success or less success were: cultural acceptance of the LeanTEC principles on a higher level than the team, proper staffing, strategic alignment, management champions / priority and selection of the right leader.

12.0 Task 9 – Supplemental Data / Analysis

The supplemental data / analysis task was added as part of the phase two plan. As additional information was developed during the course of LeanTEC program additional analysis of collected data was required to understand the new information and its connection to existing information. Often the additional information led to new questions requiring the LeanTEC team to obtain even more specific information. The execution of the "in-depth survey/analysis" task occurred at multiple points during the LeanTEC program and shown in Figure 3-2 of this report.

Supplemental surveys were conducted in support of the information obtained from a large project survey and the executive workshop. Two types of surveys were conducted, formal and informal. Included in the formal surveys were additional administrations of the survey instrument to specific project teams. The purpose of these additional surveys was not to add to the database but to obtain more data on a specific type of project or from a project that was known to have dealt with a specific issue of interest.

Another type of formal survey was the administration of a very short version of the large survey instrument to cognizant management. The purpose of the surveys was to obtain the management perspective along a known project for which information from team members had been collected for comparative purposes and to gain a deeper understanding of the various perspectives on a project. Informal surveys were conducted with members of management and selected team leaders who had significant experience in project management and technology transition. The purpose of these informal surveys was to obtain feedback and verification on the results of the executive workshop and large project survey.

Supplemental analysis of existing data was performed to assist in the understanding of the cause and effect relationships indicated by the preliminary analyses. As more information was obtained a comparison of various data sets was performed to determine what differences, if any existed among the data sets. An example of this was a comparison of the overall data set without the information from the Raytheon survey included to the data set with that information included. The result showed that the project classification (P questions) and the outcomes were essentially the same for both data sets. This allowed the use of either data set depending on the requirements of the analysis. In general, the larger set was used to obtain more significant data. However, in some instances the smaller data set was used were given variables were not included in some of the later administrations.

Supplemental in-depth analyses were also required to allow the presentation of information that dealt with several variables simultaneously. While the sample size for the large project survey (450 projects) was larger than previously seen in the literature, when conditional analyses were required the sample size often was not adequate. Once the third or fourth condition had been placed on the data set one was often down to a few cases. Supplemental analyses and surveys helped obtain information or validation of suspected results in these cases.

Specific in-depth analyses were conducted to obtain additional information on items identified by the team as having major importance to the project results. One example of this type of analysis is

the financial analysis presented in Volume 4 of the Manual for Effective Technology Transition Processes. The LeanTEC team identified the need to quantify the waste that we all knew existed in that was documented by the outcome data from the survey in terms of dollars. Since most technology transition professionals had an idea of the magnitude of the problem, the team felt that linking a "bottom line" number to the quantitative percentage data from the survey would provide more incentive to take corrective action. This led to the specific action to do in analysis that would accomplish this goal.

Another example of specific in-depth analyses was the analysis conducted on major factors related to outcome under various staffing conditions. The problem defined by the team was the identification of poor staffing as a barrier to achieving benefits from various building blocks that would have otherwise provided benefits (if proper staffing were in place). This required additional analysis of the data set from the survey. Criteria for specifying the staffing parameter, all case skills on the team and professionals not over-committed, in terms of gold, average and weak staffing. The data set was filtered for the various states of staffing. For each state, correlation of the survey variables with outcome was examined to determine which variables still provided a benefit. In other words, if one had gold staffing what would be the next items to work on. If one had weak staffing what would work and what wouldn't. And similarly for poor staffing, what could one do to improve technology transition outcomes. The results of this study are shown in Figures 12-1 and 12-2 as examples of this type of analysis.

Factors Related to Successful Transition For Various Staffing Conditions

O1 Gold		
T13 Got along personally	0.3	
T7 Small grps made progress	0.3	
T10 Members hi tech competence	0.3	
R7 Uncertain funding	-0.2	
F3 Formal progress reports?	0.3	
F2 Asked for supplier comment	0.3	
E6 Reviews at "stage-gates"	0.3	
B3 Company strategy change	-0.4	X
B19 Key benefits difficult to quantify	-0.3	
B4 Missed a window of opportunity	-0.2	X
B6 Mgt only accept minor chg	0.2	
B2 Over estimated cost benefit	-0.2	

O1 AVG		
T17 Member from procurement	0.2	
T10 Members hi tech competence	-0.2	
T20 Didnt use best ideas	-0.2	
T7 Small grps made progress	-0.1	
R10 Substantial resources from progr	0.2	
E11 Lot of customer contact	-0.2	
E5 Benefitted from other co. research	-0.2	
E1 Met w/ teams on related work	-0.2	
E8 Proj management priority	0.1	
B3 Company strategy change	-0.3	X
B24 Suppliers did not meet commitme	0.3	X
B15 New tech. solution emerged	-0.3	X
B20 Customer resisted change	-0.2	
B11 Cut backs in proj. resources	-0.2	
B4 Missed a window of opportunity	-0.2	

O1 WEAK		
T22 Key mbrs continued thru	0.4	X
T5 Link to performance rev.	0.2	X
T20 Didnt use best ideas	-0.2	
R7 Uncertain funding	-0.2	X
R10 Substantial resources from program or	0.2	
F12 Joint planning meetings?	0.3	X
F10 Used prototypes during discussions?	0.3	X
F15 Had test articles/ parts?	0.2	X
F16 Used engr drawings in face to face?	0.2	
F17 Had unsched. conversations?	0.2	
F6 Used mockups w/ suppliers?	0.2	
E8 Proj management priority	0.3	X
E12 Management champion	0.3	X
E11 Lot of customer contact	0.2	X
E2 Resisted outside ideas	0.1	
E9 Know where to get help	0.1	
B19 Key benefits difficult to quantify	-0.3	X
B3 Company strategy change	-0.3	X
B4 Missed a window of opportunity	-0.2	X
B11 Cut backs in proj. resources	-0.2	X
B22 Late crit prod. issue	0.2	
B20 Customer resisted change	-0.2	
B25 Ideas rejected by depts	-0.2	
B14 Tech wouldn't scale	-0.1	
B6 Mgt only accept minor chg	-0.1	
B24 Suppliers did not meet commitments	0.1	
B12 Testing/QA/accept. too long	0.1	

Items marked with an X are common to more than one staffing condition.

Figure 12-1. Example of Specific "In-Depth" Analysis – Transition

Factors Related to Lean Transition For Various Staffing Conditions

Gold - lean	w/o cost	w/cost
F1 Went to shop floor	0.43559	0.368248
F2 Asked for supplier comment	0.371992	0.431823
S8 Customer in proj def	0.335314	
R7R$ Certain funding		0.316092

Avg. Lean	w/o cost	w/cost
E8@4 Proj mgt priority	0.26898	
E9@4 Know where get help	0.337348	0.360581
F10 Prototypes: Many/other	0.309881	
F11 Trades: Many/other	0.281862	
F13 Mockups: Many/other	0.284532	0.429163
F14 Tools: Many/other	0.326144	0.530239
F16 Drawings: Many/other	0.244689	0.236908
F18 Stories: Many/other	0.229914	
F2 Asked for supplier comment	0.339561	0.386847
R10@4 Subst progr resources	0.281865	
R4@4 Trades used effectively	0.292749	0.252568
R6@4 Used 3D modelling	0.276877	0.325951
S9 Proj fit w/ strategy	0.22056	0.246672
T1@4 Ldr good w/ tech	0.265878	0.316566
T13@4 Got along personally	0.211742	0.333913
T19@4 Track record	0.267889	
E3@4 Mgt review helpful		0.305626
F1 Went to shop floor		0.359585
T11@4 Lder tech competence		0.351744
T22@4 Key mbrs continued		0.250012

Weak - Lean	w/o cost	w/coxt
E1@4 Met teams on related work	-0.279642	
F8 Need mangmnt to resolve diff?	-0.239729	
S8 Customer in proj def	-0.209265	-0.265987
E8@4 Proj mgt priority	0.194507	
F7 Others represented mfg view	0.215161	
S7 Hi risk/ hi pay off		-0.229419
R10@4 Subst progr resources		-0.233014
T4@4 Turnover		-0.262504

Data is shown for on time, zero or minimum late changes and meets technical goals, and also with the addition of meeting cost goals.

Yellow indicates the factor applies to more than one staffing condition as shown. Blue is unique only to the indicted staffing condition.

Figure 12-2. Example of Specific "In-Depth" Analysis – Lean Outcome

Additional analyses were also conducted on the data and information obtained from the LeanTEC experiments/pilot projects. Some of these analyses were specific analyses of data already obtained to verify or better understand observed outcomes on the pilot project. Other analyses were required to incorporate the lessons learned from the pilot projects into the LeanTEC solution elements set. The results of these analyses are included in Volume 4 of the manual and have been incorporated into the best practices / examples in Volume 3 of the manual.

As described in Section 5 of this report, the addition of barriers and enablers to the database has been ongoing activity throughout the LeanTEC program. As specific barriers and enablers were defined additional analyses were sometimes required to understand how these barrier/enabler pairs related to the existing solution set. Both formal and informal interviews with technology transition professionals were also conducted to verify or better understand the impact of the newly identified barrier/enabler pairs.

13.0 Task 10 - Disseminate the LeanTEC Information

LeanTEC information was disseminated through theses, papers and presentations. These included presentations to Lean Aerospace Initiative (LAI) meetings, the Aerospace Weekly Expo 2000, and Aerospace Industry Association (AIA) meetings. Poster sessions were held at the Defense Manufacturing Conference (DMC) and the National Aerospace Systems and Technology Conference (NASTC) as well as various “industry days” technical expositions. LeanTEC information was disseminated to various business units of participating companies through briefings and feedback sessions on survey results. A strong relationship with both LAI and AIA was established with regular reports being made available to both organizations. Members of these organizations were requested to provide transition experiences and requests for work in specific areas of interest to LeanTEC. A list of some specific LeanTEC presentations were as follows:

- DMC Q4-1999 (poster session)
- People & Organizations plenary session of the Lean Aerospace Initiative Conference on March 30th in Boston, MA. Q1-2000 (presentation)
- Boeing Assembly Technologies Colloquium 2000 on Q3-2000 in St. Louis, MO
- LeanTEC briefings, “LeanTEC, Lessons Learned Again” were presented to a joint session of the Engineering Management Committee (EMC) and Technical Operations Council (TOC) of the Aerospace Industry Association on September 19th and 20th in New Orleans. Q3-2000
- A paper jointly authored by MIT, Boeing, Pratt & Whitney and Central State University has been renamed “The Wrong Kind of Lean: Over-commitment and Under-represented Skills on Technology Teams”. This paper was submitted for publication to the IEEE Journal of Engineering Management Q3-2000
- Aviation Week Expo 2000 in Long Beach, Ca (presentation) Q4-2000.
- DMC Q4-2000 (poster session)
- Aerospace Industry Association Engineering Management Committee Q1 2001
- SME Conference at CSULB Q2-2001 (literature and discussions)
- Boeing Technology Expo in Everett, WA Q2-2001 (poster session)
- National Aerospace Systems & Technology Conference (NASTC) Q2-2001 (poster / handouts session)
- Defense Manufacturing Conference (DMC) Q4-2001 (poster session)
- Internal industry briefings and web sites (Boeing, Pratt & Whitney)
- Web site developed and maintained by CSU

In addition to the presentations above, the Quarterly Reviews / team meetings provided a mechanism for dissemination among team member organizations. These reviews included presentations to, and by, members of the host community. Feedback from these sessions was incorporated into results of the LeanTEC program where applicable. Dates / locations of the reviews / meetings were:

Event	Date	Location	Key Milestones
Kickoff Meeting	Jan-98	Boeing LB	
Kickoff Meeting	Feb-98	WPAFB (Dayton)	
Industry Days	Mar-98	WPAFB (Dayton)	
Q2 Review	Aug-98	Boeing STL	
Q3 Review	Nov-98	WPAFB (Dayton)	
Q4 Review	Jan-99	Boeing STL	
Q5 Review	May-99	Boeing STL	
Q6 Review	Aug-99	WPAFB (Dayton)	
Q7 Review	Oct-99	Boeing STL	
Team Meeting	Jan-00	Boeing LB	Phase 2/Annual Plan
Q8 Review	Mar-00	M.I.T (Boston)	
Q9 Review	May-00	WPAFB (Dayton)	
Q10 Review	Aug-00	WPAFB (Dayton)	
Q11 Review	Oct-00	WPAFB (Dayton)	
Team Meeting	Nov-00	Boeing STL	
Q12 Review	Mar-01	Boeing LB	Annual Plan
Q13 Review	May-01	WPAFB (Dayton)	
Q14 Review	Aug-01	WPAFB (Dayton)	
Team Leader Info Sessions	Q2-00		
Team Leader Info Sessions	Q3-00		
Team Leader Info Sessions	Q1-01		

The surveys, pilot projects and informal discussions with technology transition professionals provided additional opportunities for dissemination of information on LeanTEC. These sessions also provided an opportunity to get feedback and additional information both during and after the sessions. This was incorporated into the LeanTEC results where applicable.

The survey administration at each site included an overview of the LeanTEC project including goals and objectives. This overview was given at the beginning of the survey session and so contained no information on LeanTEC results, theories, opinions or anything else that could possibly bias an informant's answers. Following the survey a presentation of previous results was given along with an opportunity for open discussion on the technology transition.

The pilot projects provided many opportunities for dissemination and feedback. In each project area the team leaders were trained, the team members were provided information on the LeanTEC program, solution elements and best practices and the management of the teams was briefed on the LeanTEC program and solutions. At these sessions and at subsequent team meetings and LeanTEC intervention sessions, there was ample exchange of information and opinions.

As mentioned throughout this report, the various team members carried on extensive formal and informal talks with technology professionals. The result was both a dissemination of information from the LeanTEC team to potential users and an opportunity to obtain feedback on the LeanTEC results.

The primary mechanism for information dissemination is the LeanTEC Manual for Effective Technology Transition Processes. The format and contents of the LeanTEC manual have been

described previously in several sections of this report. Additional details on the contents and intent of each volume follows. During the various presentations many requests for draft copies of the LeanTEC manual were received. The LeanTEC team resisted disseminating preliminary copies of the LeanTEC manual or portions thereof that were not included in the briefings to anyone other than those engaged in the pilot projects. The reasoning behind this is based on one of the key survey findings that indicated a high negative correlation of success with management prematurely pushing technology into transition. This is in line with the experience of many technology transition professionals. The technology is prematurely transitioned and does not live up to the expectations of the user or provide the advertised benefit. In a few years when the technology is mature it is again brought to the user with the comment "here is the real technology". Of course the customer is very reluctant to be burned again. The LeanTEC team feels that while this manual is not the final word on the subject it certainly provides the tools required for substantial improvement in technology transition processes.

Objectives of the LeanTEC Manual:

- Provide Processes, procedures and tools to enable companies to:
  - Develop a technology transition process with guidelines for business units and project teams, or
  - Improve the current technology transition process at the corporate, business unit and project level
- Provide benefit to the enterprise through:
  - Increased likelihood of successful transitions aligned with corporate/ business unit strategies and goals
  - Decreased late transitions and late changes after transitions have occurred - reduced cycle time
  - Improved quality by meeting technical and cost goals
  - Behavior modifications promoting a Lean culture and enabling technology transitions

Target Audience

- Technology Transition Managers / Process Owners - Volumes 1,2,3,4, (5 optional)
- Management -- Executive - Volume 1
- Management - Senior - Volumes 1 and 2*, Quick Start Implementation Guide
- Management - Middle, Project Team Management Champions - Volumes 1,2, Quick Start Implementation Guide and 3*
- Project Teams -- Sponsors, Support Personnel - Volumes 1 and 2* - Self-Inventory
- Portfolio / Project Team Leaders, Core Team Members - Volumes 1,2, Quick Start Implementation Guide, 3* (4 optional) - Self-Inventory
- Customers and Stakeholders - Volumes 1 and 2*
- Managers / Leaders With a Specific Problem to Solve - Volume 3*, Volume 5 Barrier Database- Self-Inventory

* Selected Portions – using the interactive CD, areas of interest can be easily found.

Contents of the LeanTEC Manual

Volume 1 – Summary

An overview Effective Technology Transition and This Manual's Benefit to Your Organization. Answers the question "Why read this?"

Volume 2 - Stakeholders Guide To Technology Transition Processes

Process Description - Introduction to Key Building Blocks for Success
Appendix "Quick Start Implementation Guide" - Self- Inventory

Volume 3 - Technology Transition Process Implementation Manual

Details of the process, elements for success with examples, best practices and lessons learned

Volume 4 - Methodology

Detail method for customized implementation of the LeanTEC principles and background for Volume 1-3 results.

Volume 5 - Data - (CD Only - No Paper Copy)

Raw data, databases and reports - Barrier / Enabler Database for those interested in furthering the state of the art or those exploring a specific problem area in-depth.

14.0 Summary of Results

This section provides an overview of the general results from the LeanTEC program and examples of specific details. Examples of data presented in the manual are shown to demonstrate one of the major unique aspects of the LeanTEC program. That major unique aspect is the quantification of benefit (or lack thereof) of the various factors that are traditionally deemed to impact technology transition on specific outcomes. This section builds on many of the results presented in previous sections related to the specific tasks and attempts to bring them together in an orderly manner.

14.1 Solution Elements and Building Blocks

Major results of the LeanTEC program include definition of the solution elements and specification of key building blocks for success. Each of the 8 Solution Elements defined in Section 8.3 and all 72 of the Key Building Blocks for Success are briefly described below. (The Solution Elements are indicated by Roman Numerals and the Key Building Blocks are identified by capital letters.)

Solution Element I. Establish a balanced, consistent corporate technology transition process.

A A corporate Technology Transition Process with designated responsibility, accountability and authority is required
B The technology transition process must include a technology portfolio planning and management process to achieve enterprise goals by insuring alignment of individual projects with business unit portfolios and corporate strategy
C Project Processes that align with the corporate process must be established
D Lean Practices must be an integral element of ALL processes
E The "official" processes and the "actual" processes must be the same
F There must be a balance between standardized work and freedom to customize local processes
G Consistent and balanced metrics must be used enterprise wide
H Balanced Incentives must be tied to metrics and used to encourage desired behaviors
I Knowledge Capture and Continuous Process Improvement must be a part of the technology transition process at ALL levels of the organization

Solution Element II. Create an enabling environment for effective technology transition.

A The perspective of technology transition processes must be enterprise wide
B Efficient (Lean) Technology Transition must be known to be a Management Priority by employees and stakeholders
C Lean Principles must be a practiced culture in all parts of the organization
D An environment that enables accurate and efficient Cross-boundary communications and collaboration must be provided throughout the enterprise
E The view of technology transition as an investment or cost must be specified and communicated throughout the enterprise
F The goal of a technology transition project, to either provide the best technology solution or to implement a specific technology, must be specified and communicated throughout the enterprise
G The fact that having a portfolio with a mix of projects with various probabilities of technical success is desirable and planned must be communicated throughout the organization

H People must be rewarded, not punished when difficult projects are appropriately terminated
I Corporate culture must promote a balanced combination of standardized and customized process elements to achieve overall enterprise efficiency
J Best practices from other organization and companies must be customized and used when appropriate
K Project activities must be event and opportunity driven, rather than calendar driven
L Portfolio and project expectations must include consideration of both the short-term and long-term availability of adequate resources
M A culture of efficiently capturing knowledge to increase the value of the enterprise intellectual capital must exist throughout the enterprise

Solution Element III. Select Technology Transition Projects for a portfolio aligned to corporate strategies and provide supporting resources for the projects.

A Technology Transition Projects must be selected based on customer needs and both short-term and long-term business strategy
B Technology portfolio selection decisions must take the needs of all stakeholders into consideration
C The project portfolio must balance traditional and new or replacement technologies
D The technology selection process and results must be communicated throughout the organization
E Product / Technology Roadmaps must be used to drive project selection to maximize short-term and long-term enterprise value
F Technology Transition Projects must be selected by a cross-functional management team / technology council
G A formal/standardized set of analytical tools for technology portfolio assessment that addresses technical risk, strategic, financial, and business elements must be used
H Resources must be allocated and balanced in accordance with portfolio priorities and the product / technology roadmap
I Long-term investments in facilities and personnel must be aligned with the roadmap
J Shared Resources must be placed by those selecting portfolio elements
K Project and Portfolio Teams must be staffed with technically competent personnel who have the right mix of skills and experience, including leadership skills
L The right leader(s) must be selected for individual projects and groups of projects
M Team members must have enough time to commit to the project to ensure the success of the project in meeting portfolio objectives

Solution Element IV. Form a team to develop and execute a technology transition project plan.

A Management must provide the team with a complete set of skills
B All Projects must have a Management Champion
C All stakeholders must be identified and their responsibility, authority, and potential impact on project success defined
D Selected Customers and Stakeholders must participate on the team and/or in progress reviews
E Procedures and protocols must be developed to keep internal and external customers and stakeholders informed

F A team roster must identify ALL team members along with their roles and responsibilities
G The team structure and decision making protocols must be well defined and known by all team members
H Core team members must not be over-committed, with some members working full time on the project
I Team Leaders must participate in the team members' performance reviews
J Management must minimize the forced turnover of team members and not allow a premature breakup of the team near the end of the project

Solution Element V. Develop a project charter and plan/contract to ensure successful achievement of portfolio goals.

A A standard initiation process with project charters that clearly spell out objectives and expectations must be employed for each project
B The charter must include clear links between the project' goals and overall strategies that maximize the portfolio value
C The project selection, charter and plan must be agreed to up front by the team, management, the customers, and other required stakeholders
D The project plan / contract must clearly define a detailed transition plan with a planned start and completion
E Projects must have well defined and agreed to resources, success criteria, and metrics related to the portfolio objectives and roadmap
F The plan must result in a contract agreement for implementation of the technology between the customer(s) and the team/management
G The project contract / plan must be a living document with changes in project objectives and plans negotiated as conditions dictate

Solution Element VI. Establish communication / collaboration protocols to ensure efficient and accurate information flow

A Internal team procedures/ protocols for communications must be well defined and understood by all involved parties
B Protocols/Procedures for both formal and informal external team communications must be well defined and understood by all involved parties
C Communication protocols must be used to maximize accuracy, minimize misinformation and transaction costs
D Designs for knowledge capture protocols must be consistent throughout the enterprise
E Organizational standards for equipment / software must be used where practical
F Virtual team tools must be employed by both virtual and collocated teams when they produce increased benefit

Solution Element VII. Conduct activities and use representations to promote efficient execution of the plan through shared team experiences.

A Focused activities that produce a shared experience must be facilitated and used as part of project/portfolio planning and execution.

B Shared experiences among team members must be used to develop mutual respect for other team member's capabilities and technical "areas of pain"

C Physical representations must be used for efficient, shared understanding among team members

D Physical representations and focused activities must be selected, planned and coordinated with management concurrence and funding

E Focused activities and representations must add value by both contributing to the execution of the project plan or portfolio objectives and being used for team building among all team members

F Focused activities and physical representations must be an integral part of an overall enterprise strategy for knowledge capture

Solution Element VIII. Conduct formal reviews that result in a successful technology transition.

A Reviews must be a planned as an integral part of the technology transition process and project plan / contract

B Reviews must be value-added, give stakeholders an accurate assessment of the project, provide sound advice and assistance to the team, and require minimal added preparation effort from the team

C The review process must be governed by Lean Principles

D Review Metrics must be consistent with those used to measure performance on the project plan/contract, the corporate portfolio and indicate linkages to other portfolio projects when needed

E Reviews must be used for Lean termination or redirection of the project based on the agreement of critical stakeholders

F Following successful execution of the project plan, a special review must be held to achieve final resolution on an agreement by critical stakeholders to implement the technology into product production

G Selected members of the Technology Transition team must continue on the project and additional validation reviews must be held after insertion into production

H Review content and actions must be documented as a part of the corporate knowledge capture strategy

Each of the building blocks is related to one or more best practices. These best practices are illustrated in the examples in Volume 3. The self-inventory (appendix to Volume 2) lists best practices that are related to the key building blocks. This self-inventory is *not* intended to be a rating system. It *is* intended to be a tool to help users (portfolio team, project team, or team to design a new technology transition process) define areas where improvement is needed, assign priority to the selected items, and find the link to the appropriate solution element - building block examples in Volume 3. A sample of this self-inventory form is shown in Figure 14-1. It is recommended that the electronic version be used. The electronic version will allow dynamic linking between the self-inventory and Volume 3.

3.3.C.1 SOLUTION ELEMENT III - Select TT Projects for a Portfolio Aligned to Corporate Strategies and Provide Supporting Resources for the Projects -Technology Transition Process Inventory: Please enter an "X" in the box that expresses your opinion of the current state of your project / process for each concept. For **Improvement Needed / Priority/Source** Enter: **N=None, S=Some, P=Plenty / H,M or L for High Medium or Low** priority/and **I=Internal** (your Group) or **E=External** (some other Group)for the **Source-Group** for Implementation. Related Building Blocks refers to sections in Volume 3 that can be accessed for detailed information.

Performance Level	Strongly Agree	Agree	Disagree	Strongly Disagree	Improvement Needed / Priority /Source	Related Building Block
Technology projects are selected based on customer's needs and both short- and long-term business strategy.					/ /	R G III-A
Projects that do not result in value to a customer or contribute to the business strategy are not in the portfolio					/ /	III-A
Project selections reflect a balance between customer desires and corporate profitability					/ /	III-A
The project selection process is responsive to changes in strategy and market conditions					/ /	III-A
Decisions regarding technologies reflect the full spectrum of stakeholders interests(business, technical, production)					/ /	R G III-B
The selection of technology projects is balanced between traditional technologies and new or replacement technology development.					/ /	G III-C
The balance between mature and new technologies reflects the company's strategy and culture					/ /	III-C
The technology selection process is known by all those involved in technology transition					/ /	R G III-D
The technology selection results are known by all those involved in technology transition					/ /	III-D
The technology selection process is perceived as fair and balanced by all those involved in technology transition					/ /	III-D

Figure 14-1. Sample "Self-Inventory" Sheet

14.2 Key Insights

Key insights are embodied in the solution elements along with their examples. The following summary includes some building blocks having greatest impacts on Lean technology transitions.

One Size Does Not Fit All

- Use Processes and Tools That Fit Your Organization / Culture
- Minimize Waste - Maximize Value Flow

Staffing

- All Key Skills, Not Over Committed
- Continuity

Management Priority

- Priority Known, Useful Reviews
- Avoid Premature Push Into Production

Resource Allocation

- Funding & Resources - Certainty, Continuity, Adequacy
- Program(User/Customer) Participation in Providing Resources

Strategic Alignment

- Select the Right Projects to Maximize Portfolio Value
- Known Strategy, Alignment in Changing Conditions
- Risk Acceptance / Openness / Incentive to Accept Technology

Leader Selection

- Good at Getting Help, Good at Resolving Technical Differences
- Not Necessarily Technical Lead, Switch to Program Lead

Team Members

- Inclusive Teams, Open to New Ideas
- Prior History

Project Charters, Plans and Contracts

- Well Defined Expectations, Comprehensive Plans
- Up Front Planning / Commitment For Product Implementation

Communications

- Inclusive (Customer, Supplier, Program, Shop)
- Use Activities and Representations

Technical / Cost Issues

- Scale, Risk, Test & Qualification, Standards, Constraints
- Estimating Benefit, Short Production Run

<u>Key building block areas in Lean technology transition have wide applicability.</u>

Each building block area listed in this summary applies to most solution elements and across all three process cycle steps. Each building block area listed in this summary must be considered for the Lean umbrella with Continuous Process Improvement to have maximum effect. The term "Team" can be applied to the group of Technology Transition process owners, the technology councils, corporate management, program management, portfolio managers, project teams - in short to any group of people engaged in a common activity. Implementation details and best practices depend on the step in the cycle, the solution element and make up of the "team" as shown in Volume 3 of the manual. The Interactions of the building block areas and the component building blocks must be considered - they are not independent.

<u>"One Size Does Not Fit ALL".</u> This requires a conscious balance of process elements to achieve efficiency in a given organization and situation. Organizations have to select from the available solutions and modify them to fit their culture and business needs. A balance between standardized work and local customization must be achieved for a proper combination of efficiency and creativity. Maintaining proper balance is difficult since it requires a response to changing environmental factors. Lessons learned and some guidance for differences such as team

size/project complexity, risk taking culture and corporate attitude toward technology transition is given in the examples in Volume 3. The solutions exist. The difficulty is in selecting the right ones for what you are trying to do and then doing them consistently and in the right way. An example of the elements that need to be kept balanced in accordance with the business unit culture is shown in Figure 14-2.

Balance Is A Key Issue At Major Companies
It Is Difficult To Obtain and Harder To Maintain

Examples of Items Requiring Balance For Lean Technology Transition

Item	Too Much	Too Little
Process Control (Strictly Specified Standard Work)	Stifled creativity / innovation - inefficient for small projects	Chaos, inefficient due to lack of common processes
Short Term Focus	Sacrificed long term benefit	Future funding generated from current savings jeopardized
Long Term Focus	Future funding generated from current savings jeopardized	Sacrificed long term benefit
Desire to Transition (generate return from) All Projects	Concentration on low risk / low return projects	Lack of sense of urgency and good business practice
Monetary Incentives for Amount Transitioned in a Given Period	(See above) - Tendency to push projects into production before they are ready	(See above) - Late projects / failed transitions due to loss of business case
Focus On Transitioning a Specific Technology To a Specific Product	Delay due to trying to transition the wrong technology - Failure to look at other solutions	No transition plan - technology for technology's sake - "Sandbox" culture
Success Oriented Culture - Transition Rewarded / Project Termination Considered Failure	Top personnel avoid high risk/high payoff projects - Projects drag on With marginal benefit	Many high risk projects are attempted and abandoned, wasting resources - lack of accountability

Figure 14-2. One Size Does Not Fit All

<u>"Proper Staffing".</u> Staffing is a key factor in success and efficiency at ALL process levels. We must have all key skills on the team - a missing skill on the technical council or the project team can either prevent the team from achieving its goal or cause delays and rework. We must make sure the core team members can commit the required quality time to the effort, attend important meetings (all meetings in a lean environment) and focus attention on efficient completion of the team goals. Adequate quality time is required for the communication that produces accurate, efficient and creative exchanges of ideas. Turnover of key personnel and premature breakup of the team results in major disruption to the flow of value that the team, causing delay/rework. The impact of proper staffing on outcomes is shown in Figure 14-3.

<u>"Management Priority".</u> A clear set of signals identifying an activity as a management priority substantially increases the probability of success. Management priority can be achieved in a variety of ways such as:

- Statements by upper management in the "technology providing" and the "technology receiving" organizations.

- Proper staffing and consistent funding of efforts
- Obvious position of the project on the strategic roadmap
- Helpful reviews
- Special incentives / known to be a part of performance reviews
- Management pushing technology into production prematurely is another form of indicating management priority that usually results in transition, <u>but is also highly predictive of delay, many serious late changes, not meeting technical goals and not meeting cost goals</u>.

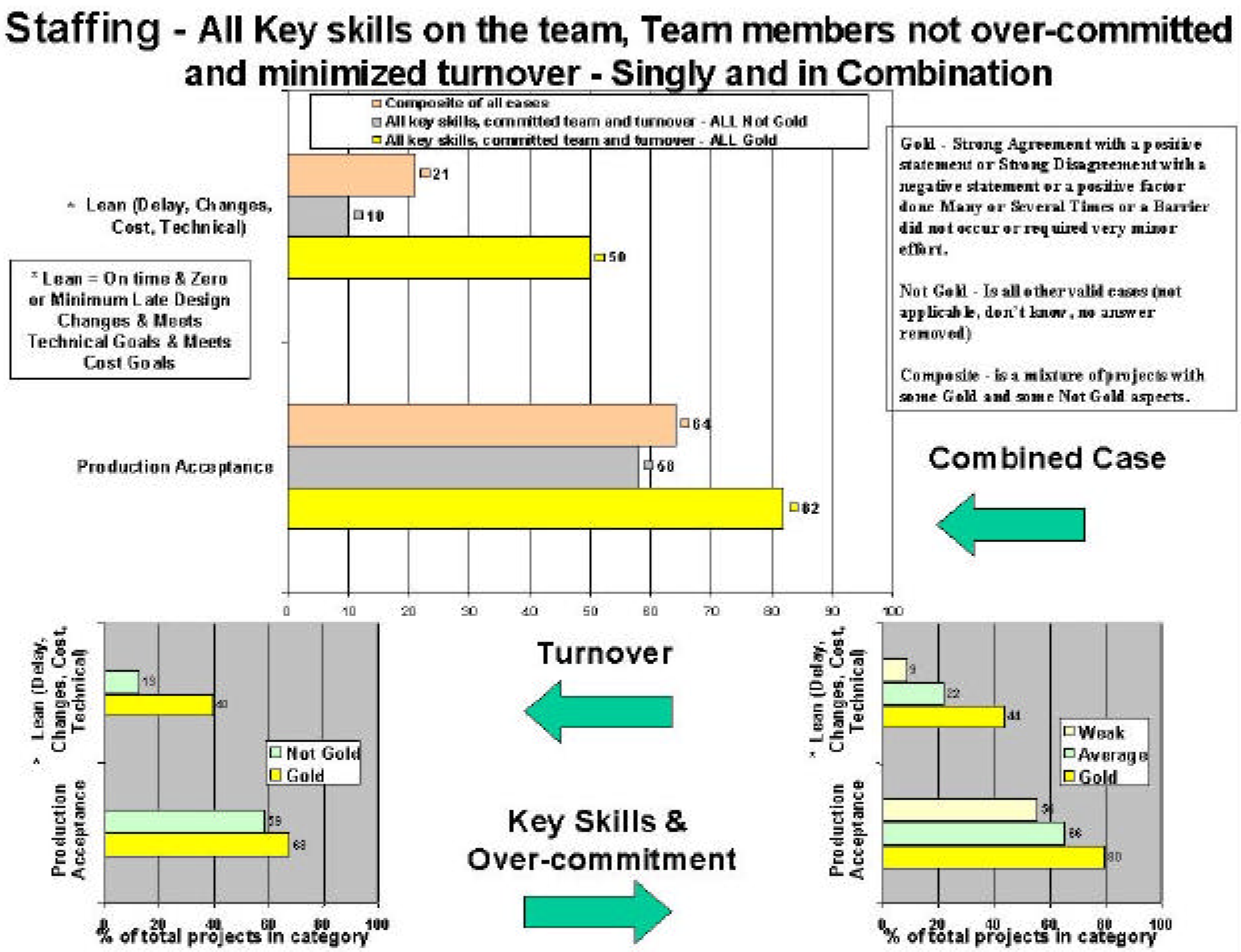


Figure 14-3. Staffing Impacts on Technology Transition Results

An analytical result of four factors measuring the impact of a management priority on technology transition is shown in Figure 14-4. The four factors considered were:

1) Was the project a management priority?
2) Did the project have a management champion?
3) Was project success a factor in individual performance reviews?
4) What effect does premature transition into production (due to management pressure) have?

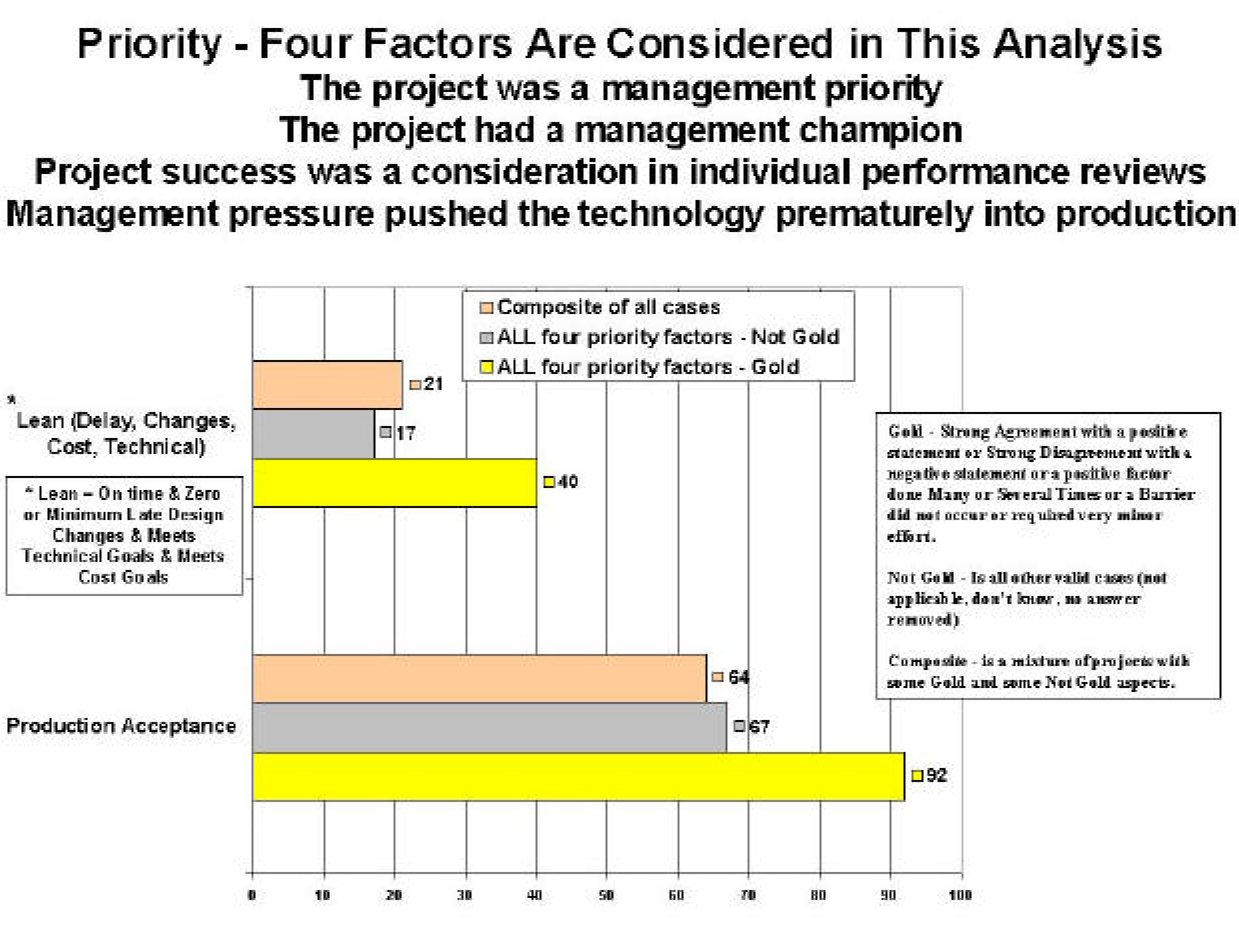


Figure 14-4. Four Major Factors Impacting Technology Transitions

<u>"Resource Allocation".</u> Providing and allocating funding and resources properly is essential to the success of individual projects and the portfolio.

Resources must be allocated among competing projects to insure the success of the portfolio goals as well as the success of individual projects. Certainty and continuity of funding is a major factor in project success and efficiency. The impact is reflected in factors that indicate team process such as meetings being frustrating as well as meeting attendance and a feeling of commitment among members. Participation of the in-house customer, production / program organizations, in supplying funding and other resources is a strong indicator of project success.
Resource allocation involves more than just funding. Team staffing and selection of people are covered under a separate building block area. Inadequate funding did not prevent transition but was a factor in the transition not being Lean. Certainty of funding was the major issue - if funding was certain it was probably adequate in most cases. Lack of certainty of funding is considered disruptive and can impact morale, commitment and staffing. Specifically, cut backs in project resources were disruptive and highly related (negatively) to both successful and Lean transitions. Some projects just died slowly because of continuing cuts. Lack of funds for tooling and equipment was related both to difficulty in transitioning and Lean transitions. Inability to use production or test facilities (shared resources) impacted the Lean aspects of transition. Allocation of support

personnel (business, secretarial, computing) that are shared among all projects must be planned and executed at the portfolio level.

The impact of three key factors related to funding is shown in Figure 14-5.

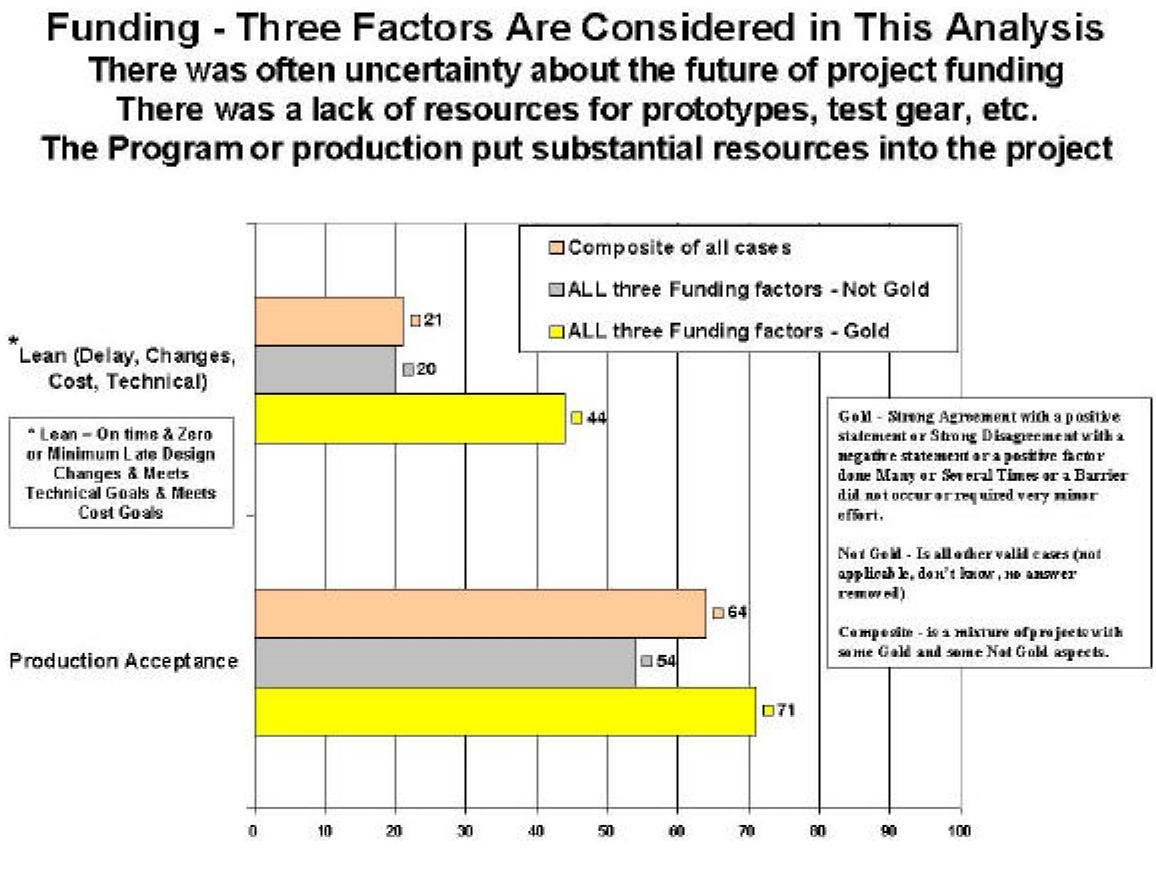


Figure 14-5. Impact of Three Key Funding Factors on Technology Transitions

<u>"Strategic Alignment"</u>. Projects must be properly selected and continuously evaluated to avoid one of the most common barriers to success, lack of Strategic Alignment.

The corporate / business unit strategy must be applied during the portfolio selection process. Information must flow to the project from management to insure that alignment is maintained during changing market conditions. Information must flow from the project to management to insure alignment during a changing technical environment. All parts of the organization involved in the portfolio / project must be aware of the strategy that caused the project to be selected to insure willingness to accept the new technology provided by the projects.

Factors related to strategic alignment that prevented transition, or a Lean transition:

- The strategy changed during the course of the project
- The window of opportunity was missed
- A new technology solution emerged during the course of the project

- Short production run when project was complete
- No management champion
- Management pushed the technology into production prematurely
- The project was not a management priority
- Not enough customer contact
- The customer resisted the change
- Funding was uncertain/resources were cut back

The impact of Strategic Alignment factors on outcomes is shown in Figure14-6.

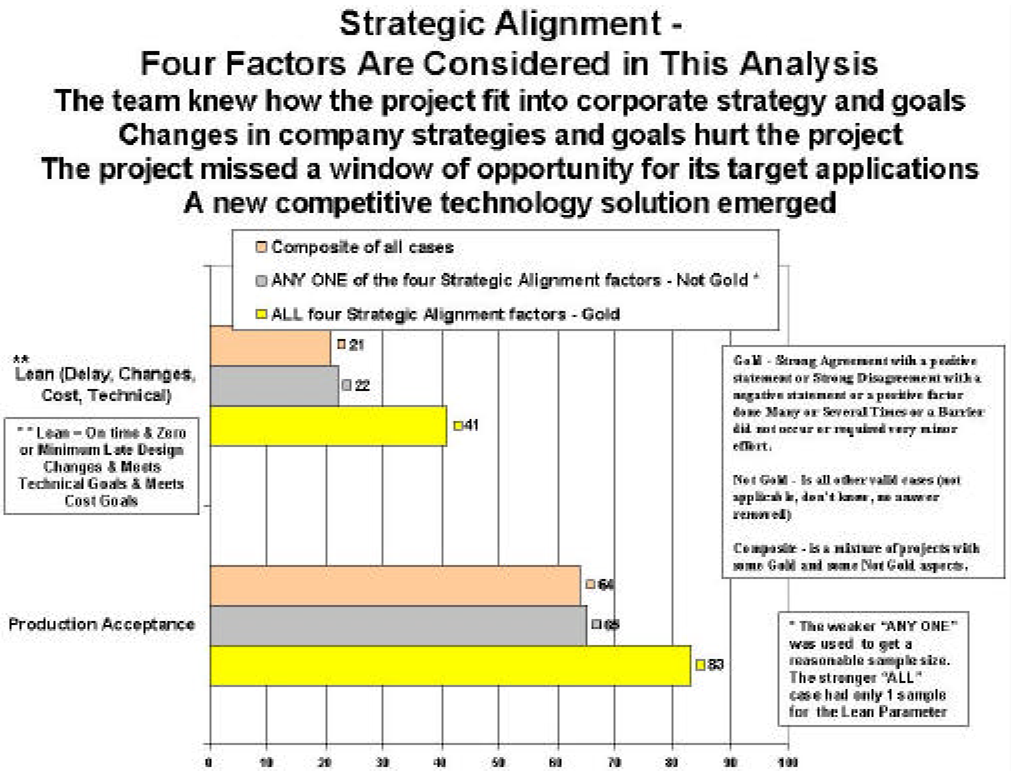


Figure 14-6. Impact of Strategic Alignment on Technology Transition Outcomes

<u>"Leader and Team Member Selection"</u>. Getting the "right" person for the job was predictive of success and efficiency in the survey and was one of the often mentioned items in project interviews. Leadership skills have more impact, both positive and negative, than membership quality on successful transition and Lean transitions. The prime characteristic of the leader is ability to resolve technical differences. Technical competence is important in a leader but the best team leader is not necessarily the technical expert or inventor. Having an overall team leader with leadership ability and a proven track record and a technical lead (inventor or expert in the field) often is the best solution. Leaders having experience in both R&D and program or production are more successful and efficient ("A" shaped or "T" shaped people). Members should be technically competent, but more important is being good at getting outside help.

Figure 14-7 shows the impact of leadership and team member characteristics on outcomes.

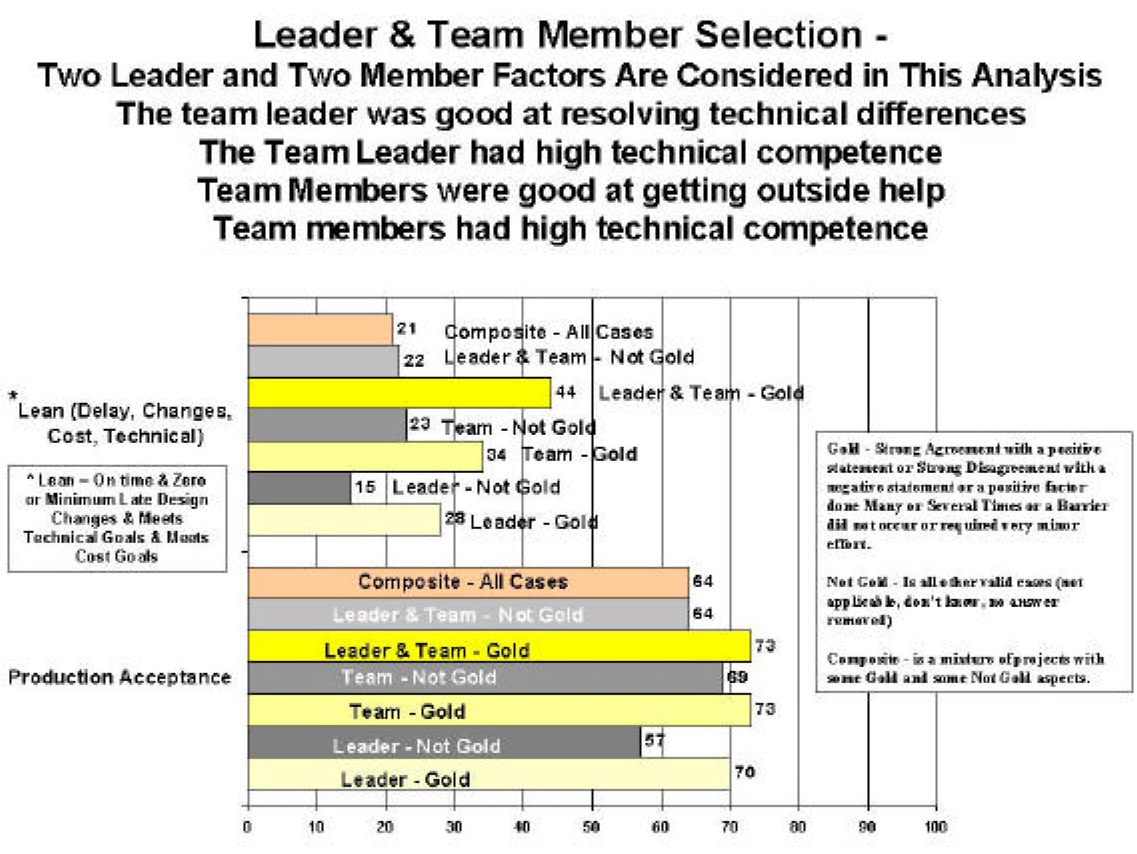


Figure 14-7. Impacts of Leaders and Team Members on Technology Transition Outcomes

<u>"Planning"</u>. Up front planning is required for efficient execution of the project including an explicit <u>Charter</u>, a comprehensive <u>Plan</u> and <u>Contract</u> insuring intent to implement the technology. The expectations for the project must be clearly stated by management - the mechanism is a charter or its equivalent. The project team must develop a comprehensive plan to meet the expectations of the charter - the plan includes a schedule that is linked to a budget for the period that starts with the acceptance of the charter and usually ends with transition of the technology to the target product. The contract is an agreement stating that satisfactory completion of the plan will lead to implementation on the target product barring any unforeseen changes in the market or technical environment. Two planning rules of thumb are: 1) Good planning usually leads to good results; and 2) a lack of planning usually leads to random results.

Key items for good planning flagged at the Executive Workshop included:

- Customer focus
- Disciplined processes
- Agreement by ALL stakeholders
- Ability to change as required
- Alignment with strategy

- Alignment with resources
- The plan is the basis for define the “Right” flow of value

“Communications”. Cross boundary communications is a known problem. Specific factors in effective communications relate to successful and efficient technology transitions. Cross boundary communication of all kinds is important, but the major benefit comes from early and frequent involvement of customers, suppliers and the shop. Frequency of communications is not as important as quality (accuracy and shared understanding). Activities and representations are critical to cross boundary communications - Trade Studies were the top activity found in the survey and mock-ups shared with suppliers were more important than prototypes as shared representations. Activities and representations need to be used early and often to be most effective.

One of the main enemies of effective communications is organizational silos and the NIH (Not Invented Here) syndrome. Overcoming these undesirable behaviors requires a culture that discourages silo building and encourages and rewards openness, sharing and cooperation throughout the enterprise. Properly applied, Lean principles can help achieve the cultural change. The LeanTEC solution set includes “shared activities”. These shared activities require groups and individuals to work together to achieve a value added common goal. This breaking down of silos at the tactical level provides a temporary cure for the symptoms of the problem, resulting in improved outcomes. Many project anecdotes dealt with how one person, due to a silo mentality or an NIH attitude caused a worthwhile project to be delayed substantially or fail.

The impact of several communications related factors on outcomes is illustrated in Figure 14-8.

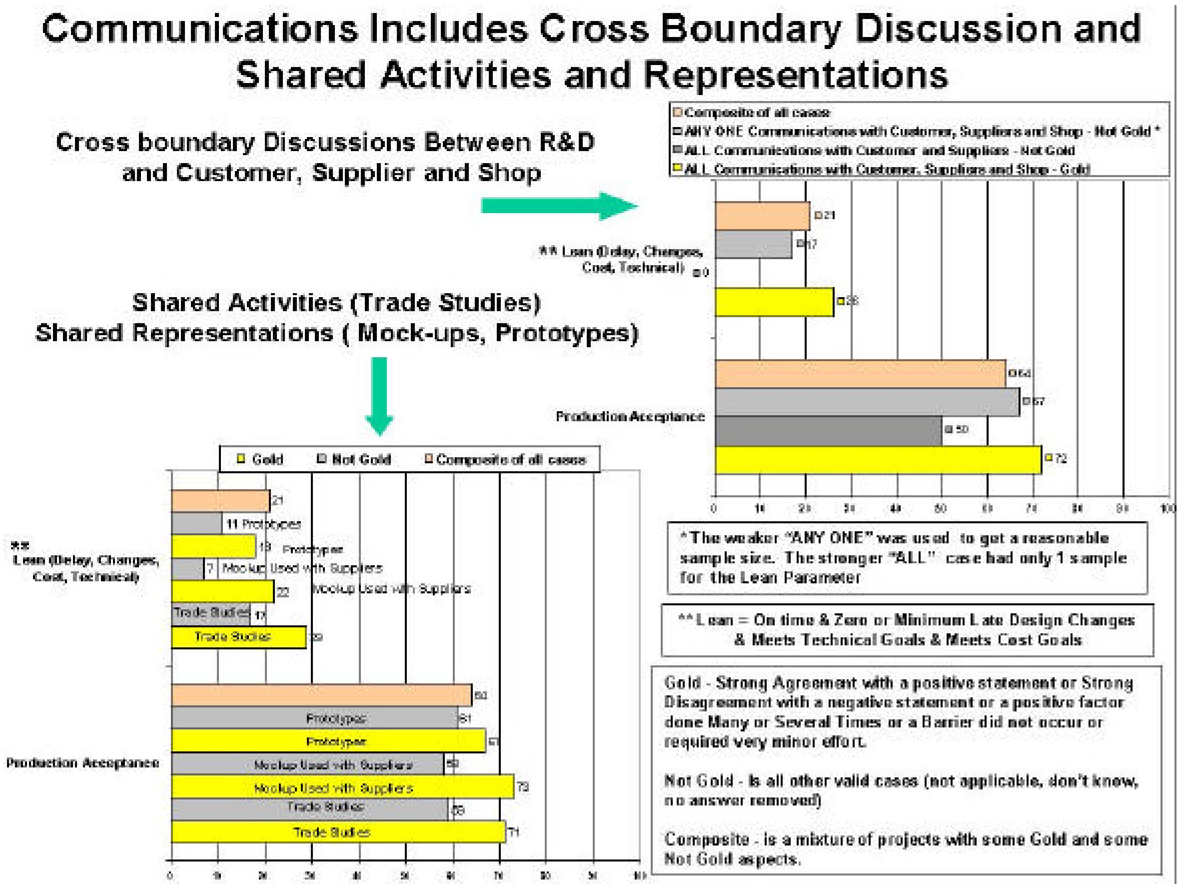


Figure 14-8. Impact of Communications on Technology Transitions

<u>"Technical and Cost Issues"</u>. Technical and Cost Issues that commonly become barriers to effective technology transition should be given special attention during project planning and risk analysis activities. The Project Survey, Executive Workshop and Project Interviews Revealed Several Technical and Cost Issues that Often Resulted in - Failure to Transition or Late Transition, Late Design Changes, Not Meeting Technical or Cost Goals. A database of over 600 barriers / enablers is in Volume 5 on the CD version of the manual. About 300 of these involve either technical or cost issues. Another 50 deal explicitly with cost, and 44 explicitly with technical issues. Planning should focus on technical and cost issues that most likely to have a negative impact on the specific project. Proper risk mitigation procedures will help define these critical issues.

Some specific technical and cost issues were found to relate to success and efficiency in technology transition for projects in general. However, many technical and cost issues are unique to a given project. Issues relating to outcomes from the experience base of the LeanTEC program pilot projects included:

- The effect of form, fit and function constraints on technology payoffs and difficulty in achieving risk reduction were major technical barriers
- The inability to quantify benefits even as transition neared was a major cost barrier
- Difficulty in achieving scale up and unexpected critical production issues provided the major technical barriers from the aspect of production

- ➢ A major barrier to meeting schedule is the length of time required for testing, acceptance and quality control functions
- ➢ Several other barriers are related to staffing, strategic alignment, management priority, funding, leadership, and communications issues

The impacts of several technical and cost issues are depicted in Figure 14-9.

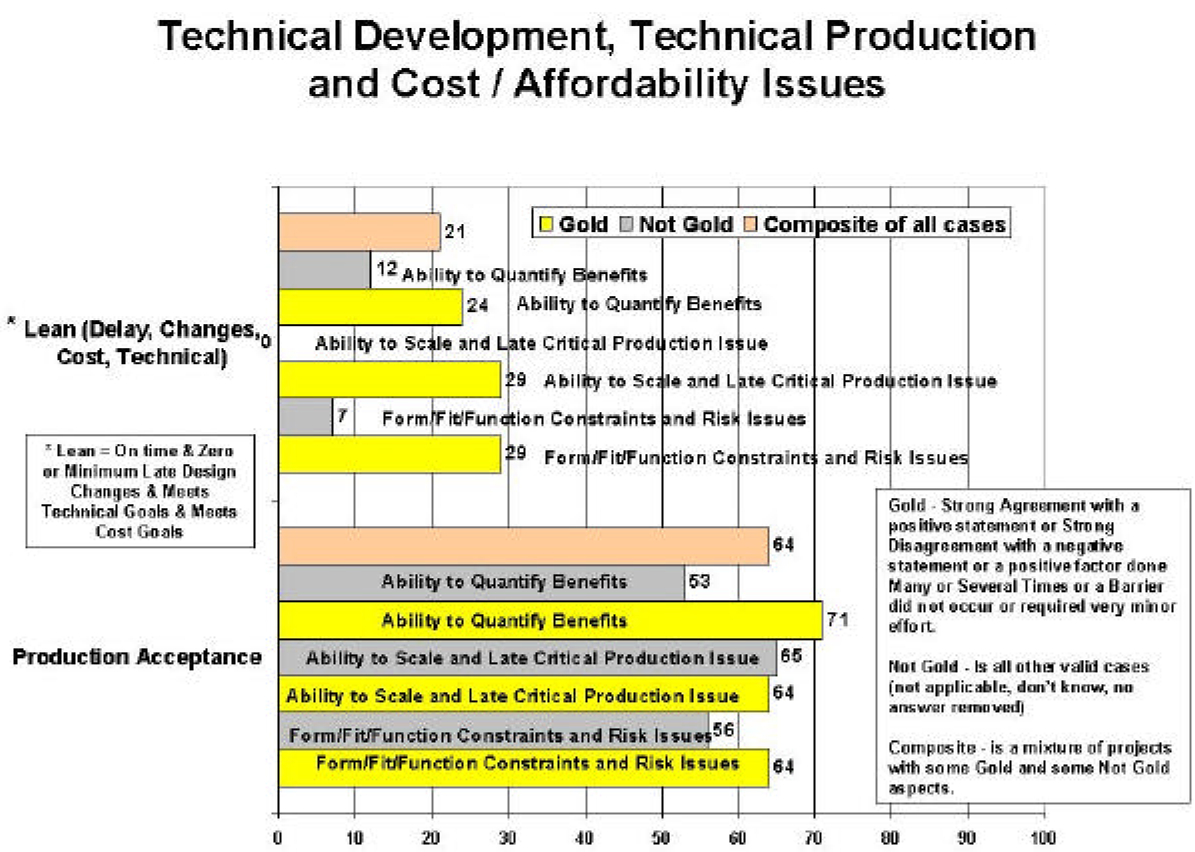


Figure 14-9. Impacts of Technology Development and Cost on Technology Transitions

An extensive treatment of the major factors related to outcomes is given in Volumes 2 and 3 of the manual. Some of the project characteristics and factors promoting transition (in addition to those discussed above) are: 1) the project had a management champion, 2) there was active government support, 3) there was government financial support, 4) substantial program resources were available, 5) funds were available for tooling / equipment, 6) there was a lot of customer contact, 7) performance reviews were linked to team performance, 8) drawings were used continually in discussions, and 9) the shop floor was continually involved in discussions.

Some team characteristics and factors that inhibit Lean transition are: testing / QA / acceptance took too long, it was hard to take the risk out, there were no agreed to acceptance standards, suppliers were not involved in discussions, trade studies were not used effectively, poor team practices (did not get along, frustrating meetings), poor staffing practices (too many tasks, turnover), poor team leadership (lacked skills, turnover), and not using prototypes, etc. in discussions.

There are several building blocks that do not show a great impact when applied singly but do show a major impact when implemented in conjunction with other building blocks as shown by the combined staffing parameter (key skills and member commitment). Analysis of the impact of combinations of several building blocks is difficult without an extremely large sample size (probably thousands). The supporting data presented in the manual used "transition to production" and "on time, zero or minimum late changes, met cost and technical goals" as measures. For custom solutions a particular business unit or project may want to evaluate the relationship of a particular building block to zero late changes only.

The results shown above provide examples of the content and benefits of implementation of the best practices, building blocks and solution elements. The selection of factors have a major impact on technology transition outcomes is based on the results all of Tasks 1 through 5 and 8 through 10 as described in the appropriate sections of this report. Survey data correlation and inputs for large numbers of professionals establish a relationship between factors and outcomes. Statements describing building block gold performance (best practices) implies cause and effect.

14.3 Experiment Verifications

The experiment results are presented in Volume 4 of the manual and summarized in Sections 10 and 11 of this report. The data collected was not sufficient to conduct the rigorous statistical analysis demonstrating with reasonable certainty that the LeanTEC solution elements, as applied, produced substantially improved outcomes. However, the information collected verified the necessity to implement an enterprise-wide process. Anecdotal information provided by individual projects demonstrated good outcomes or potentially good outcomes when the tactical portions of the LeanTEC process were embraced and used consistently. Bad or questionable outcomes for the pilot projects were largely due to the fact that the strategic and cultural aspects of the LeanTEC solution set could not be implemented in the time frame allotted. Since the projects were already ongoing some of the external factors such as change in market conditions and changes in strategy minimized the chances of these projects producing a useful output. Following the LeanTEC process, these projects were terminated for proper cause and in a timely manner thus producing a Lean outcome.

The verification of many of the concepts presented in the LeanTEC manual and the lessons learned from the pilot implementations resulted in a much improved set of processes procedures and tools. Some of the local successes were due get easy access that the projects had to people who were very familiar with not only the essentials but also the details in history of the LeanTEC solution set. This pointed to the need for substantial training of a cadre of technology transition process experts. Projects employing the LeanTEC solution set as a normal part of the team process are currently underway and are showing great promise. These are new start projects and are not subjected to the data gathering exercises conducted for the projects that were pilots in the LeanTEC experiment.

14.4 Lessons Learned

As mentioned in several of the previous sections, most of the activities associated with the LeanTEC tasks were used to both inform and obtain feedback for lessons learned. These lessons

learned appear throughout the LeanTEC manual and in many instances are seamlessly incorporated into the solution set.

14.5 Manual for Effective Technology Transition Processes

The LeanTEC manual has been described in detail in several of the preceding sections. This manual is the main source of results of the LeanTEC program. The intent of the manual is not to duplicate the documentation of an effort that is presented in this report, but to provide a useful and compelling tool that will lead to a great improvement in technology transition processes. This manual is presented in both paper and electronic format. The electronic format is recommended since it allows the user to go directly to information that is valuable to him or her without going through the entire large amount of information contained in the manual. Proper use of this manual will result in benefits to industry, government and the general population in terms of improved products provided in a reasonable time frame at the right cost.

14.6 Implementation

The Implementation of the LeanTEC solution set in detailed in the Quick Start Implementation Guide (Appendix to Volume 2 of the Manual for Effective Technology Transition Processes) and Volume 3 of that manual. The eight step process is shown in Figure 14-10.

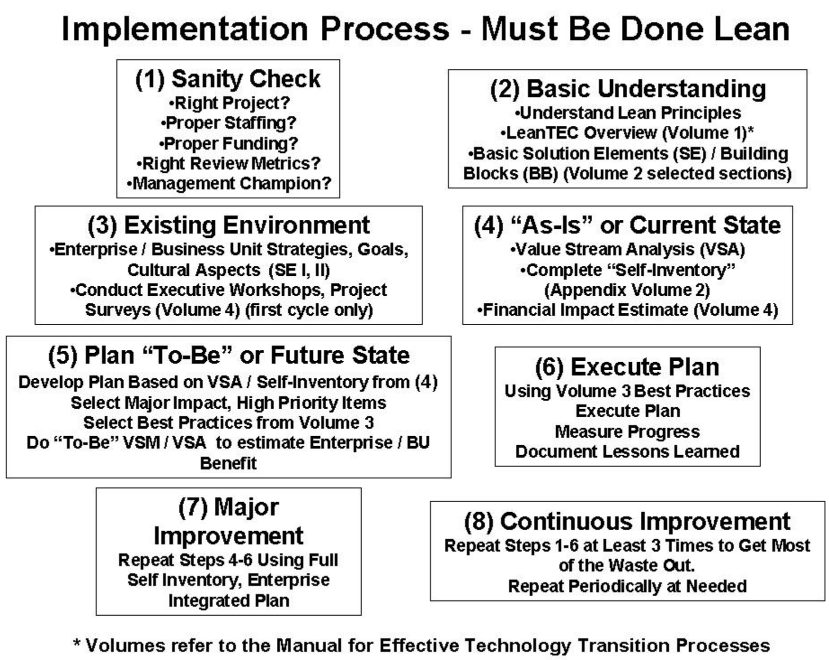


Figure 14-10. Eight-Step Lean Implementation Process

The first step is a check to see if there is strategic alignment, customer pull and the "right" critical resources. If items are not in place the remainder of the process will not work well and may not work at all. In addition to the items in step 1, a basic understanding of Lean Principles and the LeanTEC solution set is necessary from the outset to eliminate waste and rework. The user requires a reasonably comprehensive understanding provided in Volumes 1 and 2 (including appendices). Supporting management needs a basic understanding provided in Volume 1 and the

quick start guide. In additional to understanding the basic tools for improving the technology transition process the context in which the changes are to made, must be understood. This means that the strategies and goals of the enterprise and the business units must be known. The culture must be understood, especially cultural taboos. On the first round of improvement cultural taboos should be avoided. After the improvement process has demonstrated benefit and achieved buy-in, cultural taboos can be challenged where necessary. The executive workshop and project survey described in Volume 4 of the manual will give a good picture of the strategic and tactical “As-Is” condition within the context of the culture. Item deemed important to management can also be identified. The workshop and surveys are done on the first improvement pass with updates or reviews on subsequent improvement cycles.

The “As-Is” state is defined with both waste and inefficient flow paths identified by value stream mapping but cost factors are considered in the Value Stream Analysis. Financial estimates of cost of waste can be made using the methodology shown in Volume 4. The “Self-Inventory” is the centerpiece of the planning effort. Best Practices associated with key building blocks for success that are high priority items where a lot of improvement is needed can be identified. This leads to the improvement plan and the future state map. The best practices described in Volume 3 provide guidance for implementation of the selected improvements. Note The “self-inventory” is interactive allowing the user to access just the best practices associated with the selected improvement items.

The cycle should be repeated three or four times with the subsequent improvements defined by better value stream analysis and dealing with items of major importance that are unique to the company or business unit but not included in the generic LeanTEC treatment. The barrier / enabler database in Volume 5 and information in the references will help in the customization as well as the application of the LeanTEC methodology. Once the major improvement has been achieved it must be sustained by continuous process improvement.

The key to successful implementation is demonstrating a substantial improvement in technology transition, making the job of technology transition less frustrating and doing the improvement with a minimum of bureaucratic waste and inefficiency. At each cycle listen to the users / customers and improve / lean the implementation process.

14.7 Summary

The LeanTEC team has compiled extensive results that identify factors that either inhibited or enhanced Lean technology transitions on past projects. Extensive data acquisition and analyses have identified the major factors contributing to successful and Lean technology transitions. The fact that implementation of portions of the solution elements provides benefit to specific projects has been demonstrated. The solution elements do not introduce revolutionary concepts that will easily transform poor processes into world class processes. LeanTEC provides an orderly and disciplined process and recommendation for a culture that, when applied systemically and enterprise wide to the entire transition process (strategic and tactical), is projected to have major benefits to the enterprise of an order of magnitude or more. In some companies the cultural change will be radical. In others it will carry the current process consistently higher and adapt to the ever-changing technical and business environment.

“The real act of discovery consists not of finding new lands, but in seeing with new eyes.”

– Marcel Proust

15.0 Conclusions

A significant amount of money, approximately 3 1/2 percent of sales, is invested by industry each year in research and development. The government also invests a significant amount of money. The LeanTEC study has shown that over 40 percent of this investment is wasted and industry suffers over $300 billion a year in lost savings due to ineffective technology transition. The loss to the nation of the lost potential technological advantage cannot be estimated in terms of dollars.

Solutions for dramatically improving the effectiveness of technology transition from research and development to product exist. Thus far partial solutions have been implemented locally and in an inconsistent fashion producing small temporary benefits. In other words, we know many things that should be done, but until now we have not had a good handle on the factors that have major impacts on good outcomes, best practices for their implementation, nor a methodology for instituting processes and procedures that produce enterprise-wide sustainable major benefit.

The LeanTEC team has employed a methodology described in this report to identify a cyclic three-step process for effective technology transition with associated procedures and tools operating under the overarching umbrella of Lean practices and connected by continuous improvement. The LeanTEC solutions set deals with both strategic and tactical aspects of technology transition and addresses both the technical and "people" issues. The key to both effectiveness and efficiency and technology transition lies in the elimination of waste, the efficient flow of value and mistake proofing the various process steps and procedures. The key to sustained benefit is the efficient application of knowledge capture and continuous process improvement.

The LeanTEC solutions set identifies the major factors and best practices for implementation for the general issues associated with technology transition at most aerospace companies and government agencies. In Lean terms, this represents the standardized work package. The LeanTEC methodology provides the recipe for customizing the technology transition process for maximum effectiveness at a specific company, agency or business unit.

The results of the LeanTEC program are presented in the Manual for Effective Technology Transition Processes. This manual is available on CD and easy-to-use interactive format. The first volume presents an overview and compelling reasons for implementing the LeanTEC solutions set. The second volume provides an insight into the origins of the results and the basic process, solution elements and key building blocks for success. The Quick Start Guide for Implementation provides an easy-to-use start to providing benefit to either the portfolio process or a specific project process. The associated "self -inventory" provides a mechanism for identifying the key building blocks and best practices do provide maximum benefit to the specific project, portfolio or technology transition process team. The “self inventory” must be viewed as a useful planning tool for improvement and not used as a measuring stick to reward or punish people or teams. The third volume provides the details for implementation of the key building blocks and associated best practices. The fourth volume provides background material indicating the rationale for the selection of the solution elements, building blocks and best practices. This volume also provides a recipe for the methodology to customize and improve process for a given company, agency or business unit. Volume 5, available only on CD, provides a variety of information and raw data for use in developing improved technology transition processes

and solving specific problems encountered in the process of attempting to transition technology to product. This includes a searchable database of over 600 barriers and enablers.

The concept of Lean application of Lean principles is stressed throughout this report and the manual. Similarly the need to apply the LeanTEC solution set systematically and with an enterprise-wide view is stressed. Knowledge capture to feed continuous process improvement and continue the cycle of improved benefits and innovation are an integral part of each process steps and solution element.

It is concluded and has been demonstrated throughout the program that proper implementation of the LeanTEC solution set described in the Manual for Effective Technology Transition Processes will result in a major improvement in the effectiveness of technology transition. This in turn will lead to increased monetary benefit to industry (of the order of seven percent of sales) and government as well as improved technological advantage for the nation. Partial implementation of elements of the LeanTEC solution set with cognizance of the underlying concepts will generally produce a substantial benefit. Full, enterprise-wide, systematic implementation (including cultural change) will produce a major benefit for the foreseeable future.

16.0 Recommendations

It is recommended that additional analysis of the current data set the conducted to address additional questions that will become apparent as more implementations are undertaken. Additional data acquisition may also be required.

It is recommended that a survey similar to the one conducted as part of this program be repeated periodically to measure general improvement and identify new major factors that will certainly appear as technology progresses.

It is further recommended that lessons learned from additional implementations be collected and used to promote the continuous improvement of the LeanTEC solution set.

An evaluation of current commercially available tools for portfolio/project analysis and management would be useful.

The interaction of concepts such as Theory of Constraints and Six Sigma with the Lean principles should be further investigated to obtain the best enterprise-wide solutions set.

Trade studies were identified in the large project survey as a major “shared activity” that predicted good outcomes. An update to evaluate the use of newer tools to provide both a "shared activity" combined with the capability of modern knowledge capture should be undertaken.

A major effort that can be started almost immediately is identification of methods and metrics required to assess the progress of a project at various stages of the technology transition process. Methodologies for assessing technical and production readiness and CMMI (Capability Maturity Model Integration) type tools should be evaluated.

It is hoped that the industry and government communities engaged in technology transition will provide additional recommendations based on the lessons learned from implementation of the LeanTEC solution set at their specific company, agency or business unit. Continuous improvement based on the incorporation of these lessons learned, as described in the LeanTEC "To-Be" process model, will enable Technology Transition Processes to reach their full potential for providing benefit to industry, government, and the nation.